Brain Computer Interface for Real-Time Driver Drowsiness Detection

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Abstract

Drowsiness or fatigue is one of the causes of road accidents. There are many techniques in detecting drowsiness, and one of them is by detecting brainwave. Brainwave is the electrical signals which are generated by brain activity called Electroencephalography (EEG). The raw EEG signal is categorized into four main signal types depending upon frequency ranges from 0.5Hz to 30Hz. Detecting human drowsiness while driving can help reducing road accidents. In this paper, we propose the system which detects the driver's drowsiness in real-time using the non-invasive technique. By setting up the prototype of the system using the EPOC+ EMOTIV headset to collect the human's brainwaves, then monitor and analyze brainwaves to recognize the drowsiness state. The results can be modified for real applications.

Keywords: Brain computer interface; Electroencephalography; Drowsiness detection

Introduction

Today, the road accident is a significant threat that affects the safety of people. Most of the accident reports mentioned that the malfunction of the driver is the primary cause of the accident when compared to the technical failure of the vehicle [1]. Drowsiness or fatigue is a state of mind, which the response time is slower than natural levels. Main fatigue symptoms are lack of concentration ability, attention, focus, vigilance and facing difficulties to stay awake [2]. The slow reaction time is a symptom of drowsiness. Drowsiness is an essential problem, which cause an error in operations, particularly in transportation.

The primary objective of the study is to design a prototype of a real-time drowsiness detection system which could detect the drowsiness state of driver and alarm driver before they went to the state of a micro-sleep while they are driving.

Materials and methods

A. Electroencephalograph (EEG) Signals

The Electroencephalograph (EEG) signals were explored by Hans Berger, a Professor of Psychiatry at the University of Jena in Germany in the 1920s. These are electrical signals from the brain that were captured from the scalp. They are used as an essential tool for clinical diagnosis and brain research [3]. EEG Signals are a type of bio-electrical signals which are generated by the brain. There are billions of neurons inside the brain. Each neuron creates small electrical voltage fields. We can detect and record that electrical activity [4]. EEG signals are incredibly complex but have identifiable patterns depending on brain activity. Different brain states can be recognized by the frequency range of EEG signals. There are five major brain waves which are identified by their different frequency ranges. These are delta, theta. Alpha, beta, and gamma. Delta waves (below 4Hz) are associated with deep sleep. Theta waves (4-7 Hz) are characteristic for dreamlike states and old memories. Alpha waves (8-12 Hz) correspond to a relaxed state. Beta waves (13-30 Hz) are linked with alertness, arousal, concentration, and attention. Gamma waves (31-100 Hz) are associated with high mental activities, problem solving and creativity [5]. Table 1. show the Brainwave type and their related frequency range.

Table 1. *EEG Frequency bands*

Brainwave type	Frequency range
Delta	0.1 Hz to 3 Hz
Theta	4 Hz to 7 Hz
Alpha	8 Hz to 12 Hz
Beta	13Hz to 30 Hz
Gamma	31 Hz to 100 Hz

B. EEG Headset

The Brain-Computer Interface (BCI) device used for this research is the EMOTIV EPOC+. The EMOTIV EPOC+ is a high-resolution signal acquisition and wireless processing headset that monitors 14 channels of EEG data and a gyroscope for two-dimensional control.

Figure 1. *The EMOTIV EPOC+ headset.*

The electrodes are located at the positions AF3, F7, F3, FC5, T7, P7, O1, O2, P8, T8, FC6, F4, F8, AF4 according to the International 10–20 system, forming seven sets of symmetric channels. Two reference electrodes located just above the ears (one for the left hemisphere and another one is for the right hemisphere of the head) as shown Figure. 2. The idea that we choose this device in our setup is because it has been used as a real-time brain EEG scanner by many research group as demonstrated in many recent publications. The EMOTIV EPOC+ consists of 14 wet electrodes but requires less time for preparation before use. All electrodes must be placed in the correct position. The headset internally samples at a frequency of 2048 Hz, which then lower down to 128 Hz sampling frequency per channel as shown in Figure. 3, and sends via Bluetooth the data. In order to use the headset, all felt pads of the sensors must be moistened on top with a saline solution [6].

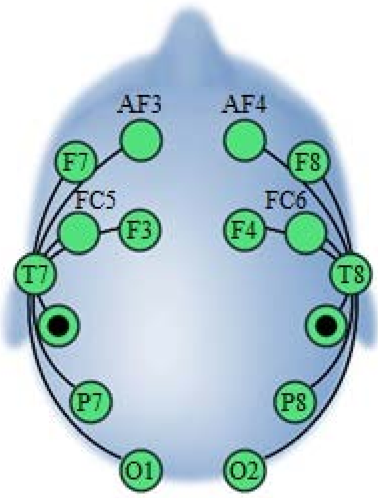

Figure 2. *The position of electrodes.*

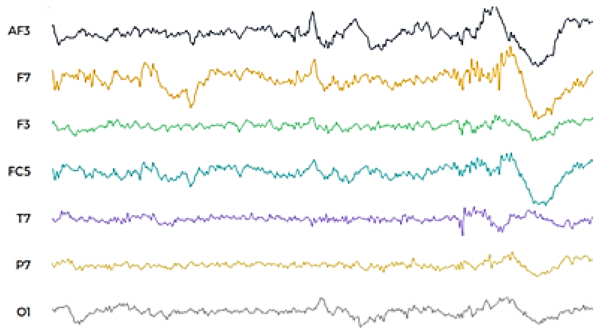

Figure 3. *The frequency per channel.*

C. Four main phases of BCI

BCI application consists of four main phases: Data Acquisition, Preprocessing, Feature Extraction, and Classification. Data Acquisition phase is the first phase which consists of capturing the signals from the brain by acquiring the signal directly from the scalp through the EEG headset device. Since the human brain signals are mostly contaminated by artifacts, which cause noisy components that interfere with the recorded signals during the acquisition process. The preprocessing phase is the phase that elimination of these artifacts from the brain signals occurred and the quality of the signals are enhanced. Many mathematical techniques are employed to enhance the quality of a signal such as Common Average Reference (CAR), Principal Components Analysis (PCA), A Common Spatial Pattern (CSP), and Scalp surface Laplacian (SL). In feature extraction phase, many techniques are used for feature extraction such as Wavelet Transformation (WT), AR, and FT. This phase consists of extracting the relevant characteristics of a signal [7]. The last phase, classification phase, brain signals is classified and identify the state of human.

D. Drowsiness

Drowsiness is one of four states of sleep which is a transition between the awake state and light sleep state. During this state, as seen in Table 2., the activity of the neurons is similar to those waking hours [8].

Table 2. *The states of sleep*

States	Frequency range
Awake	15 Hz to 50 Hz
Drowsiness	4 Hz to 8 Hz
Light sleep	4 Hz to 15 Hz
Deep sleep	2 Hz to 4 Hz
Very deep sleep	0.5 Hz to 2 Hz

E. A Proposed system

In our approach, we aim to detect the driver drowsiness state from the EEG signals. The system consists of 2 modules. The first module is called Collecting Module (CM) which id collecting brain data or EEG signal from the driver using EPOC+ headset. EEG signals of the driver were sent to the second module, called the Processing Module (PM) as seen in Figure 4.

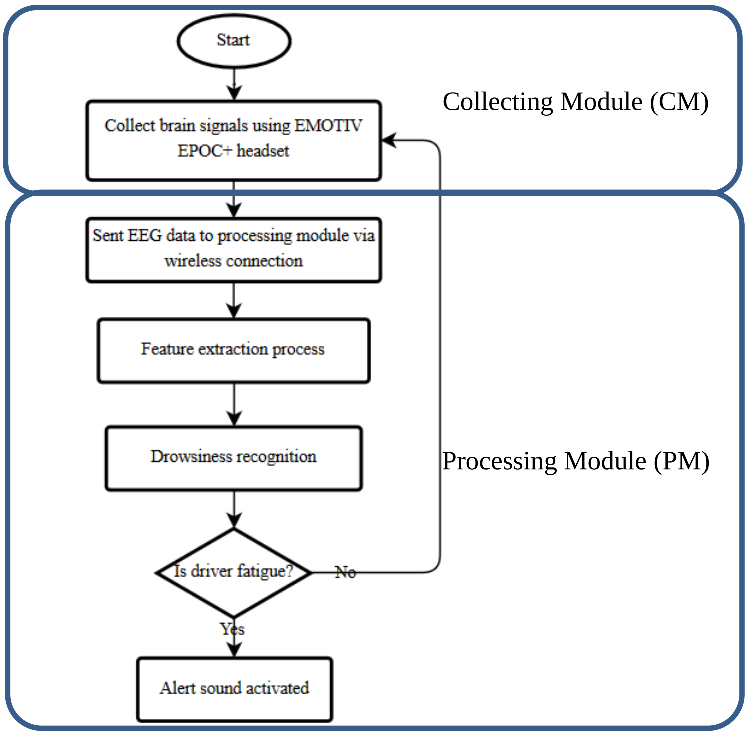

Figure 4. *The proposed system.*

After the PM received EEG signals from CM, the EEG signals are filtered with removal of artifacts and the quality is enhanced. Features are extracted from EEG signals in the feature extraction process. These features are measured by drowsiness recognition process to predict if the driver is drowsiness. If the state of the driver is drowsiness, the PM will alert by beep sound to prevent the driver go to the sleep state.

In the case of the drowsiness recognition process, we recognize by using the calculation of power value of all the band and their ratio [9]. We analyze the power ration of four different wavebands on EEG signal: Delta (0.1 Hz to 3 Hz) Theta (4 Hz to 7 Hz) Alpha (8 Hz to 12 Hz) Beta (13Hz to 30 Hz) as seen in Table 3.

Table 3. *The Power Ratio of Wavebands*

States	(Theta+Alpha)/Beta	(Theta+Beta)/Alpha	(Alpha+Beta)/Theta
Normal	3.89	0.62	4.58
Awake	3.77	0.57	5.51
Drowsiness	3.09	0.77	4.23
Sleepiness	4.17	0.95	2.41

From table 3, the transformation of the power ratio of Beta waves and the sum power of Alpha and Theta waves is not very intense, but it is comfortable to be identified. When normal state enters the waking state, there is little change. When waking state enters drowsiness state, there is a large fall. when waking state comes the sleepy state, there is a substantial rise again; From normal state to drowsiness state, the ratio has decreased, but from normal state to the sleepy state, the ratio has quickly increased; the power ratio of Theta waves and the sum power of Alpha and Beta waves are stable, From the normal state to the drowsiness state, the ratio is mainly concentrated in between 0.5 and 1, there is almost no fluctuation; when waking state enters the sleepy state, the fall is very big, about 1.5 or so. The threshold value of (Theta+Alpha)/Beta was set as 3.2, and when the power ratio of (Theta+Alpha)/Beta is less than 3.2, the driver is at the drowsiness state. If that ratio equal or greater than 3.3, the driver is not at the drowsiness state.

Results and discussion

In this work, we proposed the prototype of the drowsiness detection system. We set up the hardware and software to detect drowsiness state of the driver. Since this study is still in the prototyping phase, the real-time driving environment is not used in this time, so it has been investigated in the simulation environment, i.e. driving simulation car in the simulator. Five volunteers, ages between 25 to 35 with at least one year driving experience was selected for testing our system. They are seated on comfort seat of the simulator with EMOTIV EPOC+ headset on and drove a simulator car for one hour after having lunch. As soon as they were observed to be in the state of drowsiness, the beep sound was activated. After driving, the subjects were asked to confirm their driving states and the recorded is shown in Table 4.

Table 4. *Example of test records*

Test No.	Start time	End time	Drowsiness time	Driver State Detection	Volunteer Confirmation
1	13.00	14.00	13.40	Drowsiness	Yes
2	13.05	14.05	-	Normal	Yes
3	13.30	14.30	13.50	Drowsiness	No

To test the prototype of the drowsiness detection system, each subject was test twice. In total there are ten sets of data in the experiment. Table 5 shows the test result. In normal driving test: the state of drowsiness was not detected, the results are correct only 50%, but in drowsiness driving test: the state of drowsiness was detected, the result that marked as correct are 83.33% but marked as wrong 16.67%. Although the result of normal driving that marked as wrong is higher, but overall results that marked as correct is up to 70%.

Table 5. *The test results*

Result	Total	Correct	Wrong
Normal driving	4	2	2
Drowsiness driving	6	5	1
Overall	**10**	**7**	**3**

In this study, although we used the EMOTIV EPOC+ that is high price to buy, is high cost to implement when comparing to other systems which is proposed in other researches, the advantages of this headset are 14 channels of electrode, can provide the high-quality real time raw EEG data. However, in future work, this study must be improved the analysis and classification technique such as support vector machine (SVM) and K nearest neighborhood (KNN) for high accuracy result.

Conclusions

The prototype of the real-time drowsiness detection system was developed for this study. The concept proved that it is possible to prevent people’s micro sleeping by drowsiness detection. The EMOTIV EPOC+ headset is used to measure the human brainwave signals. The drowsiness state of human can be analyzed and recognized by the power ratio of different band calculation. In case the driver is going to drowsiness state, the user was alerted by beep sound from this system. Results show that the system efficiently in the test with 70% accuracy. The approach that we used in this study can be used for other application which is want to detect the human drowsiness state such as in medical filed.

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