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An integrated alcoholic index using tunable-Q wavelet transform based features extracted from EEG signals for diagnosis of alcoholism

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A B S T R A C T

Alcoholism affects the structure and functioning of brain. Electroencephalogram (EEG) signals can depict the state of brain. The EEG signals are ensemble of various neuronal activity recorded from different scalp regions having different characteristics and very low magnitude in microvolts. These factors make human interpretation difficult and time consuming to analyze these signals. Moreover, these highly varying EEG signals are susceptible to inter/intra variability errors. So, a Computer-Aided Diagnosis (CAD) can be used to identify the alcoholic and normal subjects accurately. However, the EEG signals exhibit nonlinear and non-stationary properties. Therefore, it needs much effort in deciphering the diagnostic evidence from them using linear time and frequency-domain methods. The nonlinear parameters together with time-frequency/scale domain methods can help to detect tiny changes in the EEG signals. The correntropy is nonlinear indicator which characterizes the dynamic behavior of EEG signals in time-scale domain. In this paper, we present a new way for diagnosis of alcoholism using Tunable-Q Wavelet Transform (TQWT) based features derived from EEG signals. The feature extraction is performed using TQWT based decomposition and extracting Centered Correntropy (CC) from the forth decomposed detail sub-band. The Principal Component Analysis (PCA) is used for feature reduction followed by Least Square-Support Vector Machine (LS-SVM) for classifying normal and alcoholic EEG signals. In order to make sure reliable classification performance, 10-fold cross-validation scheme is adopted. Our proposed system is able to diagnose the alcoholic and normal EEG signals, with an average accuracy of 97.02%, sensitivity of 96.53%, specificity of 97.50% and Matthews correlation coefficient of 0.9494 for Q-factor (Q) varying between 3 and 8 using RBF kernel function. Also, we have established a novel Alcoholism Risk Index (ARI) using three clinically significant features to discriminate the given classes by means of a single number. This system can be used for automated diagnosis and monitoring of alcoholic subjects to evaluate the effect of treatment.

1. Introduction

Acute and chronic alcoholism is accepted as a mental sickness by the Diagnostic and Statistical Manual of Mental Disorders [27]. As per 2014 World Health Organization (WHO) report, it is estimated that about 16% of the global population aged 15 years or more are heavily engaged in consuming alcohol [75]. It is reported that, 5.9% of total death is due to alcoholism amounting to 3.3 million. Alcoholism is the fifth major cause of mortality worldwide [46]. It is the dominating risk factor for early alcohol-related death and morbidity [20]. Moreover, it is reported that alcohol abuse considerably rises Disability Adjusted Life Year (DALY) and even leads to death [74]. The cases of alcohol-related diseases such as cancers of liver, esophagus, oral, etc. are increasing at an alarming rate and hence there is a the need to prevent it [16].

The subjects suffering from alcoholism are obsessed with drinking alcohol. Usually, these patients have difficulty in controlling their desire for alcohol despite knowing its harmful effects. Consequently, this addiction leads to serious health problem and affects the personal and social relationships at home, work place,

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and social gatherings [50]. The main cause of alcoholism include genetic, psychological, and environmental factors. Excessive drinking of alcohol leads to behavioral, cognitive, and physiological changes in the subject. It affects all the organs of a human body mainly the central and peripheral nervous systems [49,21]. Even moderate drinking can cause serious impairment of cognitive functions like acquiring, storing, retrieving, and making use of information [22]. Continuous cognitive dysfunction may cause inability to perform well at job. It can adversely affect the learning and academic performance in adolescents engaged in chronic heavy drinking [33]. The health of heavy drinkers may have irreversible brain-damage syndromes like Wernicke–Korsakoff syndrome, a disorder which is characterized by patient's incapability to remember new things for more than few seconds [52]. Prolonged heavy alcohol drinking may cause contraction of the brain and diffuse white matter defects [58]. In view of these, early detection of alcoholism can ensure effective treatment of alcoholism affected subjects thereby saving life and preventing the risk of disability and death [3]. Even the need for reporting alcoholism is also important in other specific clinical applications. It is very useful to identify parents with alcohol abuse which can transmit alcohol related pathologies to the foetus. The regular excessive intake of alcohol may alter the liver functionality and may cause fatty liver disease and ultimately lead to cirrhosis. Hence, there is a need to detect the alcoholism accurately by a noninvasive method.

It is difficult to recognize the cases of alcoholism using conventional methods [3]. Generally, it is diagnosed in clinics and primary heath care hospitals by assessing the responses to irritation by criticism, cutting down, guilty feeling, and first drink in the dawn [3,51]. However, it is found that the rate of positive screening of alcoholic subjects using these questions is lower than 50% [28]. This may be attributed to few patients not disclosing the correct information due to shame and anxiety of stigmatization. On the other hand, electroencephalogram (EEG) signals acquired non-invasively depicts the state of brain and can be used effectively for detection, identification and treatment monitoring of alcoholic patients [3,43].

A lot of research has been conducted to explore and establish the impact of alcohol on EEG signals so that they can be used for neurophysiological assessment. These studies have shown significant clinical correlation between alcohol use and EEG signals. The alcoholic subjects showed variation in the power spectrums of the alpha (8–12 Hz), beta (12–30 Hz), gamma (>30 Hz), theta (4–7 Hz), and delta (0–4 Hz) frequency bands in EEG signals. In conjunction with these effects, the patient experiences behavioral changes like hallucinations and seizures [15]. By pointing out the power level variation of these frequency bands in EEG signals, neurophysiological assessment can be made. Studies on alcoholics have shown that EEG signals exhibit higher theta wave [59], delta wave, and beta wave [60] power as compared to control subjects. Increase in the beta 1 (12–16 Hz), beta 2 (16–20 Hz), and beta 3 (20–28 Hz) frequencies of the EEG signals are related to frontal and parietal region of alcoholic subjects [61]. The outcome of Bauer's study on alcoholic subjects also showed an increase in beta activity within frequency range from 19.5 to 39.8 Hz [10]. Alcohol when taken in lower dose below 0.5 g/kg has been found to impact the task-related synchronization in theta frequency band of EEG signals [19]. And moderate alcohol dose increases the power of the alpha band (8–12 Hz) [19]. With changes in EEG alpha activity, topographic localization, generalized cortical processes and morphological nature within brain gets modified [11]. A high alcohol dose exceeding 1.0 g/kg increases the activity of EEG frequencies below 8 Hz [44,47]. For high alcohol dose, lower spectral power of delta and fast beta have been observed in non-binge and low-binge drinkers in contrast to high-binge drinkers [14] and added synchronization in theta as well as gamma frequency bands [12].

Manually, it is quite complex to point out the fine variations in EEG signals between normal and alcoholic subjects for the diagnosis of alcoholism even by a trained medical expert. Clinical interpretation of EEG signals involves analysis of variations in the EEG frequency spectrum which in turn requires lot of experience and skill. Moreover, these subtle variations are difficult to inspect by naked eye as the amplitude is in micro volts. It is strenuous, time consuming and may suffer inter/intra observer variability. The Computer-Aided Diagnostic (CAD) systems involving the application of cutting-edge signal processing and artificial intelligence are found to provide excellent consistent results in diagnosing the disease using the EEG signals [24,18,42,41,40,78].

In CAD based diagnosis, signal processing techniques such as wavelet transforms [36,34,39,55], nonlinear dynamics, and chaos theory [77,63,6] are widely used in features extraction. Moreover, artificial intelligence algorithms such as neural networks [35,73,13], Principal Component Analysis (PCA) [5], Support Vector Machine (SVM) [45], and enhanced probabilistic networks are used to capture minute changes in the signal and automated diagnosis of diseases. The linear [60,59,61] and nonlinear methods like largest Lyapunov Exponent (LLE), entropies [4], Hurst exponent (H)and Fractal Dimension (FD) are extracted to detect the deviation from the normalcy [6].

In this paper, we put forward a new method to automatically diagnose alcoholic EEG signals using Centered Correntropy (*CC*) based features resulting from Tunable-*Q* Wavelet Transform (TQWT). Recently, Ivan W. Selesnick proposed the TQWT for flexible study and processing of oscillatory signals in time-scale domain [66]. The features based on wavelet coefficients of TQWT are utilized to represent the dynamical changes in the alcoholic EEG signals. Basically, the correntropy measures the pairwise correlation among the time-delayed input feature vectors in a nonlinear way. [64]. Moreover, it reflects the geometry of the group of points in the feature space [64,29]. The correntropy can be used to represent the minute changes in the nonlinear EEG signals by nonlinearly mapping the detail wavelet coefficients into high dimensional space by means of kernel function. These projected features in the high dimension space can yield useful clinical features. Therefore, in this work, the proposed raw features *CC* are calculated from specific decomposed detail sub-band. The proposed method involves TQWT based decomposition of EEG signals up to certain level. Then, the coefficients of detail sub-band in this level is used to extract correntropy based features. The resulting features are reduced using PCA. The reduced feature set is fed to LS-SVM classifier for classification of normal and alcoholic EEG signals. The classification is done using three different kernel functions that are radial basis function (RBF), Morlet and Mexican hat wavelet kernel functions with 10-fold cross-validation. The effect of *Q*-factor (*Q*) on classification performance is investigated to find the optimal value of *Q*. In this work, a novel Alcoholism Risk Index (ARI), an integrated index is devised from three principal components to discriminate the two classes via a single number. The proposed index can assist the clinicians during diagnosis and treatment monitoring of alcoholic patients.

This paper is organized in five sections. The methodology is explained in Section 2. Section 3 presents the experimental results of the proposed method. Experimental results are discussed in Section 4 and finally paper is concluded in Section 5.

2. Methods

The key subsections of the proposed methodology consist of: dataset used, TQWT based decomposition, feature extraction, feature reduction and LS-SVM based classification. The detailed description of each subsection is provided below.