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An efficient sleep scoring system based on EEG signal using complex-valued machine learning algorithms

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ABSTRACT

Sleep staging is a significant step in the diagnosis and treatment of sleep disorders. Sleep scoring is a time-consuming and difficult process. Given that sleep scoring requires expert knowledge, it is generally undertaken by sleep experts. In this study, a new hybrid machine learning method consisting of complex-valued nonlinear features (CVNF) and a complex-valued neural network (CVANN) has been presented for automatic sleep scoring using single channel electroencephalography (EEG) signals. First of all, we should note that in this context, nine nonlinear features have been obtained as those are often preferred for the classification of EEG signals. These obtained features were then converted into a complex-valued number format using a phase encoding method. In this way, a new complex-valued feature set was obtained for sleep scoring. The obtained attributes have been presented as input to the CVANN algorithm. We have used a number of different statistical parameters during the evaluation process. The results that have been obtained are based on two sleep standards: Rechtschaffen & Kales (R&K) and American Academy of Sleep Medicine (AASM). Finally, a 91.57% accuracy rate was obtained according to R&K standard; a 93.84% accuracy rate was obtained according to the AASM standard using the proposed method. We therefore observed that the proposed method is promising in terms of the sleep scoring.

1. Introduction

Besides being a state of inactivity providing restoration to the rest of the organism, sleep prepares the whole body for a period of renewal. Sleep forms a part of everyday life in terms of carrying out a restoration process in the body. In many of the studies that have been carried out, it is seen that in deep sleep, protein synthesis, cell mitosis and the, secretion of growth hormone are increased in the body, whereas the secretion of catabolic hormones such as adrenaline and corticosteroids are decreased [1].

Regular sleep increases the performance of the body, whereas chronic insomnia reduces its work rate and limits mental abilities. During the sleep stage, the daily wear on the majority of the organism, such as with regard to the central nervous system, and the respiratory, circulatory and musculoskeletal system, is repaired. Sleep staging is thus a significant step in the diagnosis and treatment of sleep disorders. Therefore, sleep staging is an important and intensely investigated subject [2].

Sleep staging determines the stages of sleep with the help of polysomnographic recording (PSG) during sleep itself. These records include the EEG, electrooculogram (EOG) and electromyography (EMG) data of the patient and these records are evaluated by experts based on R&K standards [3]. According to these standards, there are six sleep stages: awake (AW), rapid eye movement (REM) and non-rapid eye movement (NREM S1-S4). Recently, NREM S3 and NREM S4 have been combined, and this composite stage has been called the slow wave sleep stage (SWS) [4].

In sleep studies, EEG signals are the most frequently to record physiological signals because they best reflect brain activity [5–7]. EEG signals are composed of waves which have different frequency bands such as delta (0–3.99 Hz), theta (4–7.99 Hz), alpha (8–12.99 Hz), beta (13–30 Hz), spindle (12–14 Hz), sawtooth (2–6 Hz) and k-complex (0.5–1.5 Hz). EEG signals are characterised by different waves or features with regard to different sleep stages. The characteristic waves and features of these signals for the various sleep stages are given in Table 1. The EEG signals obtained during the various sleep stages are presented in Fig. 1.

When carried out by specialists, manual sleep staging is a time-consuming process; ordinarily it requires hours to score the PSG record of a whole night's sleep. The visual analysis of the PSG records uses a 30-s period of time and allows the classification of sleep stages. In addition, this process is a somewhat subjective one in that the visual scoring results can differ between experts. Consequently, an effective sleep scoring system can save time and provide objective sleep evaluation, independent of the subjective

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interpretation by experts [8]. To this end, a hybrid method consisting of CVNF and CVANN is proposed in this study for automatic sleep scoring. This method is called CVNF+CVANN.

The organisation of the paper is as follows. In Section 2, brief information has been given about the studies presented in the literature relating to the classification of sleep stages. In addition, in this section, we explore differences between the proposed method and existing methods, while also citing the innovations offered in terms of our proposed method. Information about the method and data set used in the study is given in Section 3. In Section 4, the experiments performed, the evaluation procedures, the experimental results and discussions are given. Finally, in Section 5, information is given about the results of this study, as well as information about planned targets for the future.

Table 1
Characteristic waves or features of EEG signals for different sleep stages.

Sleep stage	Characteristic wave
Awake	Alpha (8–12.99 Hz), Beta (13–30 Hz)
NREM S1	Theta (4–7.99 Hz)
NREM S2	Sleep spindles (12–14 Hz), k-complexes (1 Hz)
NREM S3	Delta (0–3.99 Hz)
NREM S4	Delta (0–3.99 Hz)
REM	Alpha (8–12.99 Hz), Beta (13–30 Hz), Theta (4–7.99 Hz), Sawtooth waves (2–6 Hz)

2. Related research

There are many studies presented in the literature with regard to the classification of sleep stages. We can provide brief information about these studies as follows. In his study, Sinha [9] classified 3 sleep stages (sleep spindles, REM and AW) taking advantage of wavelet transform and artificial neural network (ANN) procedures. He achieved a 95.35% accuracy rate with the proposed method. Chapotot and Becq [10] obtained features for sleep scoring using the robust feature extraction method. The features so obtained were then classified using a hybrid method consisting of flexible decision rules algorithms and ANN. They achieved a 78% accuracy rate in the study, in which 6 different stages (AW, shallow sleep, transitional sleep, deep sleep, paradoxical sleep and movement time) were classified. Subasi et al. [11] classified 3 different sleep stages (alert, drowsy, sleep) using EEG signals. High accuracy rates were achieved in the study in which a wavelet-based ANN algorithm was used as the classification algorithm. As a result, the classification success of sleep, drowsy and alert stages was 92.3%, 96.2% and 93.6% respectively. Zoubek et al. [12] used EEG, EMG and EOG signals for sleep scoring. They used Fourier transform coefficients, entropy, Kurtosis and standard deviation values during the feature extraction stage. In this study in which ANN was preferred as the classification algorithm, 5 different sleep stages (AW, NREM S1 and S2, REM and paradoxical sleep) were classified with an 80% accuracy rate.

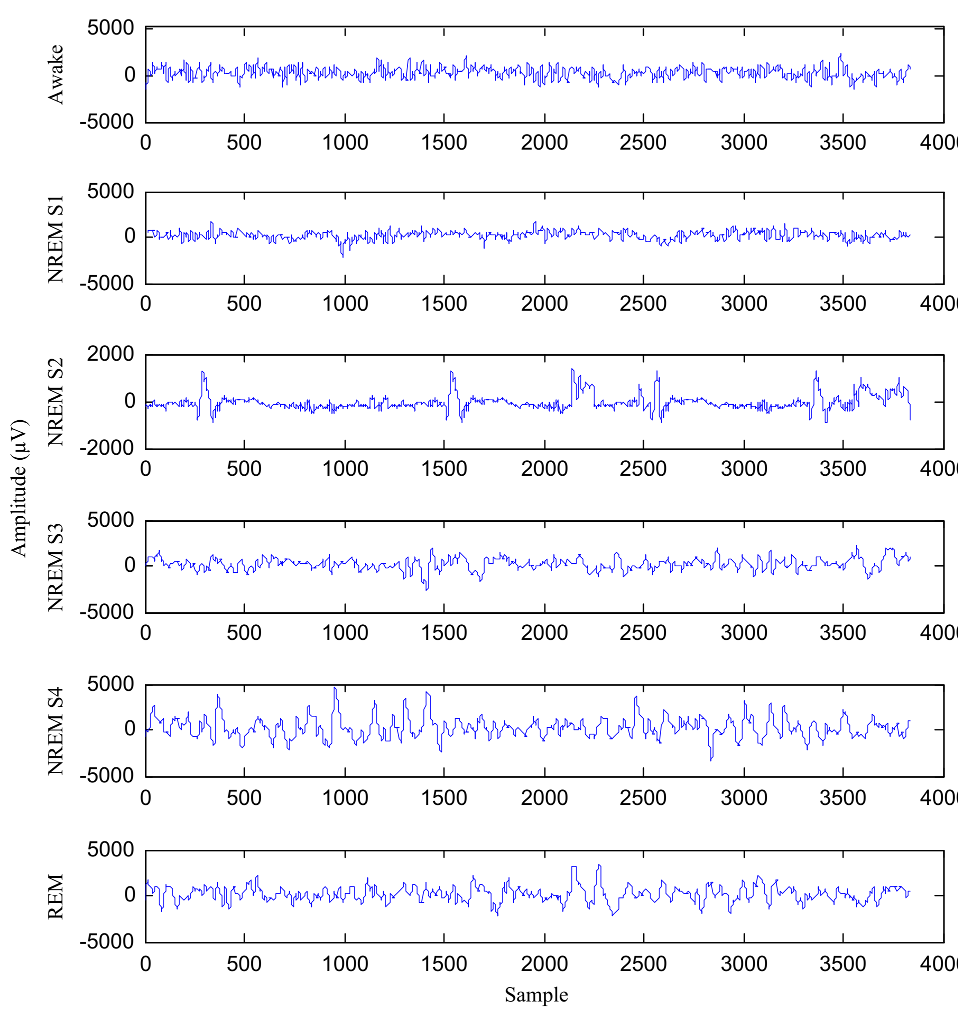

Fig. 1. EEG epochs of different sleep stages.