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Application of Wavelet Transform in The Construction of Short-term Memory EEG Information Transmission Model

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Abstract: Wavelet transform is an analysis method that combines time, frequency (or scale) domains. It has: (1) Multi-resolution; (2) The relative bandwidth is constant; (3) Proper selection of basic wavelet can make wavelet have the ability to represent the local characteristics of signals in both time and frequency domains, and it is known as "the microscope for analyzing signals". An analysis method of EEG signal based on autoregressive model (ARM) and wavelet transform is proposed, and it is used to eliminate noise interference in EEG signal. Wavelet transform is a multi-resolution time scale analysis method, which can divide the signal into sub-band signals of different frequency bands. According to this characteristic of wavelet transform, the EEG signals obtained by sampling are decomposed and denoised at various scales, and the results of decomposition and denoising at various scales are given. Wavelet transform can effectively remove noise interference from EEG signals. Wavelet transform is a multi resolution time scale analysis method that can divide signals into subband signals of different frequency bands. According to this characteristic of wavelet transform, the sampled EEG signal is decomposed and denoised at various scales, and the decomposition and denoising results at each scale are given. Wavelet transform can effectively remove noise interference from EEG signals.

Keywords: Wavelet transform, Short-term memory, EEG information transmission.

1. Introduction

Electroencephalogram (EEG) signal is non-stationary and easily disturbed by various noises, so how to eliminate the noises in the original EEG data to better obtain useful information reflecting brain activity and state is an important prerequisite for EEG analysis [1]. The traditional computer automatic analysis method of EEG signal is based on the classical Fourier transform, because Fourier transform is only suitable for deterministic stationary signals, but it has not been satisfactory for EEG signal processing with strong non-stationarity [2]. In order to solve this problem, windowed Fourier transform is used in engineering technology, but when this method is used, the finer the resolution in time domain, the more blurred it will be in frequency domain. or vice versa, Dallas to the auditorium EEG attention state recognition is an important part of EEG biofeedback, which has many applications in clinical medicine, such as treating attention deficit hyperactivity disorder (ADHD), autism (ASD), epilepsy and so on [3].

Currently, there are two main algorithms for recognizing the attention level of brain states using spectral analysis methods: one is calculation θ/β Ratio to obtain brain attention level status; The other is to decompose the EEG signal into δ Wave (≤ 4Hz) θ Wave (4-8Hz) α Wave (8-15Hz) β For waves (12 to 30 Hz) and other waves (≥ 30 Hz), the energy or power spectrum of each wave band is used as feedback information, such as Wigner Ferry distribution, matching tracking method, etc. [4]. There are many studies on automatic sleep staging based on multichannel signals. The optimal accuracy in the experiment reached 83.7%; Patanaik et al. use short-time Fourier transform to extract time-frequency maps from multi-channel EEG and EEG signals, and use deep convolutional neural networks (CNN) and multi-layer perceptual mechanisms to model, enabling real-time sleep staging [5]. In addition, sleep state recognition is also an important objective indicator for studying sleep disorders, Parkinson's disease, epilepsy, and other related diseases, and has important significance for analyzing sleep quality [6].

At present, sleep state recognition is mainly based on electroencephalogram (EEG) signal method, which has important clinical significance and wide application prospect [7]. Wavelet transform is a time-frequency analysis method that combines time and frequency domains, and it has the ability to characterize the local characteristics of signals in both time-frequency domains [8].

This article first introduces the wavelet transform methods used in the denoising process of EEG signals, and briefly introduces the AR model and order estimation. Then, based on the multiresolution analysis of EEG signals, the noise is treated as data that conforms to the AR model. In the experiment, the parameters of the AR model are estimated using the pure noise of the first 200 ms, and then the noisy signal is whitened and filtered. Then, a 5-layer decomposition of the db5 wavelet is performed to reconstruct the signal that contains large noise levels d1, d2, and d3, Perform an inverse whitening process to remove most of the noise. The effectiveness of the above method is also verified by comparing the power spectrum estimation of experimental results.

2. Construction and Analysis of EEG Information Transmission Model for Short-term Memory

2.1. The principle of classification and recognition of single channel sleep EEG signals

Therefore, sleep disorder has become a prominent problem that threatens the world public [9]. On the other hand, in order to solve the problem of N1 state misclassification and high-frequency noise remaining in sleep EEG signal after wavelet denoising, this paper gives full play to WKCNN's ability to extract frequency-domain features of one-dimensional data and its ability to suppress high-frequency noise. However, when a single WKCNN extracts features, there is the problem of time-series information loss, and LSTM can be used to describe the output of continuous states in time and has the advantage of memorizing time-series signals [10]. Therefore, in this paper, WKCNN and LSTM are cascaded into WKCNN-LSTM model to extract more comprehensive and abundant sleep EEG signal features for state recognition. The principle of this method is shown in Figure 1.

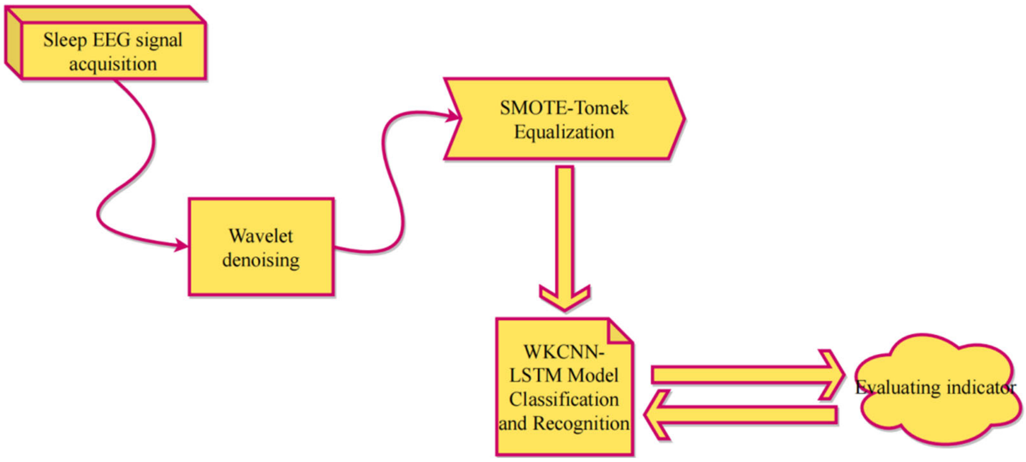

Figure 1. Schematic diagram of sleep EEG signal classification

First, select a single channel sleep EEG signal from the Sleep EDF dataset; Secondly, wavelet denoising is used to denoise the original sleep EEG signal to eliminate noise interference in the sleep EEG signal, and SMOTE-Tomek algorithm is used to construct a balanced dataset; Finally, the preprocessed sleep EEG signal is used as the input data of the one-dimensional WKCNN-LSTM model to train the model. The model structure and parameters are optimized through evaluation indicators to achieve accurate recognition of different sleep states.

Although the sleep staging model based on multi-channel physiological signals can get high accuracy, it is a direction worth exploring to adopt single-channel physiological signals for sleep staging to ensure the same level of accuracy, while reducing the difficulty of physiological signal acquisition and computational complexity. Compared with the abstract features extracted from the original EEG signal by CNN, the time-frequency domain features of EEG can be extracted more intuitively and effectively by signal analysis method. Most of the existing studies are based on small data sets, which has short data collection period and high data stability. However, in practical large-scale applications, there are often some differences in different batches of sleep data, so the accuracy and stability of the model are poor.

2.2. Theory and algorithm of wavelet transform

The basic idea of wavelet transform is to use a family of functions to represent or approximate a signal or function, which is called a wavelet function system. It is formed by the translation and expansion of a basic wavelet, and its transform coefficients can be used to describe the original signal. The prominent feature of the representation of wavelet function systems is that their time bandwidth and frequency bandwidth products are very small, and they are concentrated in both time and frequency.

Practically, in order to calculate wavelet transform, we often use Mallat fast algorithm. Mallat fast algorithm is equivalent to FFT in classical Fourier transform in wavelet analysis. This requires the introduction of the concept of spatial partition. The space where the original $x(n)$ is located is defined as V_0, and then it is divided into two parts, resulting in a high-frequency subspace W_1 and a low-frequency subspace V_1…… .

This subspace partitioning process can be recorded as:

$$V_0=V_1 \oplus W_1; V_1=V_2 \oplus W_2; \ldots\ldots V_{j-1}=V_j \oplus W_j \quad (1)$$

Where each W_j is a high-frequency subspace reflecting the details of the V_{j-1} spatial signal, and V_j is a low-frequency subspace reflecting the general situation of the V_{j-1} spatial signal.

The entire software is a Windows application developed in Windows 3.1. The Windows environment can provide three important and most basic services. First, it performs basic input and output functions, and is responsible for dealing with devices such as keyboards, mice, displays, and printers; The second is memory management. The Windows memory management API allows programs to transparently access expanded memory and extended memory; The third basic task of Windows is to support multitasking, which allows two or more programs to share CPU, memory, and I/O devices. The Windows environment can achieve better order than MS-DOS applications, allowing developers to focus on the implementation of program functions and make the program structure reasonable and highly modular; For users, Windows applications have a similar appearance and the same command structure, making them easier to learn and use than regular MS-DOS programs. The specific steps of applying the method of wavelet decomposition and reconstruction for noise elimination are as follows: According to needs, the signal containing noise is decomposed into different frequency bands at a certain scale, and then the frequency band where the noise resides is set to zero (or the frequency band where the useful signal resides is directly extracted), and wavelet reconstruction is performed to achieve the purpose of noise elimination. In the process of EEG signal denoising, wavelet transform methods commonly used include nonlinear wavelet transform threshold denoising, wavelet transform modulus maximum method, and so on.

3. Application of Wavelet Transform in The Construction of EEG Information Transmission Model for Short-term Memory

3.1. AR model and order estimation

In the process of clinical non-invasive acquisition of sleep EEG signals, there will be interference such as baseline drift and noise, which will make the local mixing of the original sleep EEG signals more serious. In order to eliminate the influence of interference noise, this paper uses Daube-chies (Db) series wavelet to remove noise and preserve the original characteristics of the signals to the maximum extent. There are several common methods to solve the parameters of AR model. For example, autocorrelation method or YuleWalker method is to obtain the parameters estimated by AR model by solving Yule Walker equation with different algorithms; The Burg method uses Levinson recursion to estimate the reflection coefficient, so as to determine the parameters of the AR model. Commonly used methods include covariance method and modified covariance method. Almost all model order estimation methods are based on the estimation of prediction error power. Usually, the estimated prediction error power decreases with the increase of model order, or remains unchanged. However, we can't simply take the reduction of monitoring and forecasting power as a method to determine the order of the model, and we must also consider the increase of variance of spectral estimation when the number of model parameters increases. Uneven data distribution will lead to excessive attention to multi-class samples in the process of model learning, resulting in low recognition rate of minority state, which not only leads to insufficient learning of minority state characteristics, but also affects the overall classification effect of the model.

In order to solve the problem of state imbalance, this article uses the SMOTE-Tomek algorithm to preprocess the dataset, allowing W, N1, N3, and REM to obtain the same number of samples as N2. This alleviates the state imbalance of the sleep EEG signal dataset without changing the dimensions. Almost all model order estimation methods are based on estimating the prediction error power. Generally, the estimated prediction error power decreases or remains unchanged as the model order increases. However, it is not possible to simply consider the reduction of the monitoring and prediction power as a method for determining the order of the model. It is also necessary to consider the increase in the spectral estimation variance as the number of model parameters increases. In order to determine the impact of the size of time sampling points on the performance of the model obtained from continuous wavelet transform (CWT), a comparative experiment with different time sampling points was conducted. The original time-frequency diagram has a sampling time of 30s and a sampling frequency of 100Hz. The number of time sampling points obtained by multiplying the sampling time by the sampling frequency is 3000 (100Hz × 30s). The data with the original time sampling points of 3000 is compressed into the original 1/200, 1/100, 1/50, 1/30, 1/25, 1/20, 1/15, and 1/12 by adding a window to obtain the average value. The new time frequency graph time sampling points are 15, 30, 60, 100, 120, 150, 200, and 250, respectively. The experimental results are shown in Figure 2.

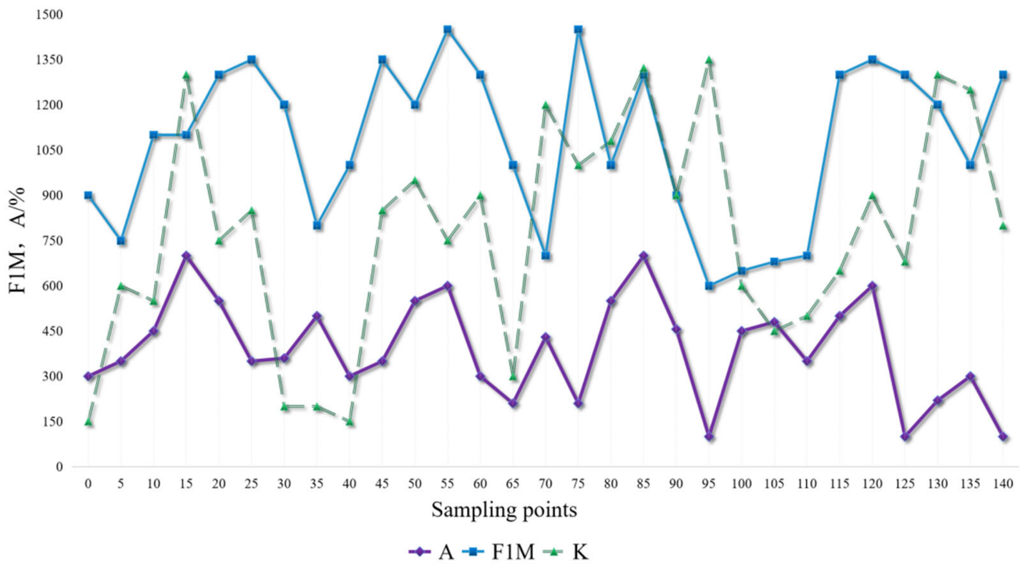

Figure 2. Experimental Results of Sampling Points at Different Times

The experimental results show that the model performance is low when the number of time sampling points is less than 200, and the model performance reaches the highest when the number of time sampling points is equal to 200, and the model performance is no longer obviously improved when it exceeds 200, so the time sampling points are finally determined to be 200.

3.2. Results analysis and discussion

When wavelet transform is used to denoise EEG signals, different wavelet basis functions are selected, and the decomposed EEG signals are different, and the denoising effect is also different. Therefore, how to choose wavelet basis function according to the selection criteria of wavelet basis function and the characteristics of the signal to be analyzed is a problem that should be considered in wavelet application. Describe several basic concepts of wavelet characteristics: support width, orthogonality, symmetry, regularity and so on. In the first stage of training two-dimensional convolutional neural network, the data expansion algorithm is used to strengthen the learning ability of the model for small sample categories, and the model is further adjusted by fine-tuning method. In order to prove the effectiveness of data expansion and two-step training algorithm, experiments are designed and carried out, and the results are shown in Table 3. No expansion means that data expansion and two-step training algorithm are not used, and the model directly takes continuous sequence data as input for one-step training; Replication expansion refers to the data expansion algorithm used in this paper, which uses replication to expand data and uses two-step training algorithm to complete model training. For example, EOG and power frequency interference signals are removed, and the collected data is passed through a low-pass filter to filter out other power frequency interference greater than 50Hz. In order to solve the abnormal correction of EEG signal, the original EEG sample points collected by subjects were replaced by the sample mean multiplied by 0.95 and the sample mean multiplied by 0.05, respectively, to complete the abnormal point correction.

According to the above algorithm, a program based on Matlab language was written, and a noisy signal M0729001 recorded in an experiment was denoised. After reconstruction of layers a5, d4, and d5, inverse whitening filtering is performed, and the results are shown in Figure 1. Select db5 wavelet for 5-layer decomposition, and the noise is mainly concentrated in d1, d2, and d3 layers (as shown in Figure 2). From the figure, it can be seen that this method can eliminate most of the noise while also locating the mutation points of the original signal. Therefore, how to select wavelet basis functions based on the selection criteria of wavelet basis functions and the characteristics of the signal to be analyzed is a problem that should be considered in wavelet applications. Describes several basic concepts of wavelet properties: support width, orthogonality, symmetry, regularity, and so on. The results show that the method and model in this paper achieve the best results on the evaluation indicators ACC and MF1, reaching a better level and significantly improving.

4. Conclusions

From the waveform of EEG signal after wavelet transform, it can be seen that the signals of each scale not only reflect the frequency information of the signal, that is, the larger the scale, the lower the frequency of the corresponding signal, but also reflect the time information of the signal, that is, reflect the state of EEG at this time. However, the traditional Fourier analysis can only obtain the whole spectrum of the signal, but can not reflect the time domain information. The simulation results show that the denoising effect of wavelet transform analysis method is satisfactory and has great flexibility. The time-frequency domain information is extracted by using the two-dimensional convolutional network based on VG Gnet, and then the sleep state transition rules are effectively extracted and sleep stages are carried out by using Bilstm. Aiming at the uneven number of sleep stages in data sets, a data expansion and two-step training algorithm training model were adopted and tested on large data sets. The accuracy rate of sleep stage 5 classification A reached 85.82%, and F1M reached 78.39, κ Up to 0.799. When using wavelet analysis methods, it is necessary to consider the impact of different wavelet bases on the processing results, because using different wavelet basis functions, the effect of EEG signal decomposition and reconstruction is also different.

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