Examination of Temporal Characteristic of Wavelet Subbands of Scalp Epileptic EEG Based on the Local Min-Max

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Abstract—In this paper, the temporal characteristic of wavelet subbands of scalp EEG of an epilepsy patient associated with different states of the brain is examined using the so-called number of local min-max. The computational results show that during the seizure onset the number of local min-max of the \(D_1\) subband extremely increases while the number of local min-max of the \(A_3\) subband remarkably drops. In addition, there are significant differences in the number of local min-max of epileptic EEG during the epileptic seizure event compared to other brain states. This suggests that the number of local min-max may be used as a useful feature for epileptic seizure detection.

Index Terms—electroencephalogram, seizure, epilepsy, wavelet subband local min-max.

I. INTRODUCTION

Epilepsy is a common brain disorder in which clusters of neurons signal abnormally [1]. More than 50 million individuals worldwide, about 1% of the world’s population are affected by epilepsy [2]. In epilepsy, the normal pattern of neuronal activity is disturbed, causing strange sensations, emotions, and behavior, that sometimes include convulsions, muscle spasms, and loss of consciousness [1]. There are many possible causes for seizures ranging from illness to brain damage to abnormal brain development [1], and epileptic seizures are manifestations of epilepsy [3]. The electroencephalogram (EEG) is a signal that quantifies the electrical activity of the brain, usually from scalp recordings and is commonly used to assess and detect brain abnormalities, and is crucial for the diagnosis of epilepsy [1].

Temporal patterns of EEG signals can provide important information and such features can be obtained by visual inspection/analysis and using computational tools. Concepts and computational tools derived from the study of complex systems including nonlinear dynamics have gained increasing interest for applications in biology and medicine [4]. The correlation integral and dimension are common nonlinear dynamical analysis techniques that have been applied to EEG signal analysis [5] to study various aspects. Epilepsy is an important application for nonlinear EEG analysis [6], [7].

In this paper, the temporal characteristic of sleep EEG quantified in terms of local minima and local maxima is examined. Local minima and maxima may be defined in various manners. In general, local min-max detection algorithms rely on thresholding the magnitudes in a specified time window. In this study, the local minima (local maxima) is defined as a point whose amplitude is less (greater) than its neighbors. The local minima and maxima thus specify extreme points of the signal where the magnitude changes direction [8]. This computational analysis technique was previously applied to analyze epileptic EEG and sleep EEG data using measures based on various characteristics of the local min-max [9]–[12].

The temporal characteristic of scalp epileptic EEG is quantified from the total number of both local minima and local maxima, referred to as the number of local min-max \(N_\lambda\). In addition, rather than analyzing the full spectral band of epileptic EEG, the computational analysis is applied to wavelet subbands of epileptic EEG signal that are reconstructed from detail and approximate coefficients of epileptic EEG signal. From the computational results, it is observed that for various wavelet subbands there are distinguishable temporal characteristics of the epileptic EEG associated with different pathological brain states as measured using the number of local min-max \(N_\lambda\). Furthermore, the most remarkable temporal characteristics of the epileptic EEG signal can be noticed in the lower and highest frequency subbands where as the number of local min-max \(N_\lambda\) of the epileptic EEG signal during epileptic seizure is significantly different from that associated with other brain states.

II. METHODS

A. Data and Subjects

The EEG data analyzed in this study were obtained from the CHB-MIT scalp EEG database [13]. This database consists of EEG recordings from pediatric subjects with intractable seizures at the Children’s Hospital Boston [13]. The EEG data were recorded using a sampling frequency of 256 Hz with 16-bit resolution A/D. In addition, these recordings used the international 10-20 systems of EEG electrode positions and nomenclature [13].

B. Local Min-Max and Local Min-Max Feature

As defined in [9]–[12], the local minima \(\lambda_{\min}\) of the signal \(x\) are defined as point whose amplitude is less than that of its consecutive preceding and succeeding points while the local maxima \(\lambda_{\max}\) are defined as point whose amplitude is greater than that of its consecutive preceding and succeeding points.

Let \(x[n]\) be a sequence of EEG samples where \(n = 0, 1, \ldots, N?1\), and \(N\) denotes the length of signal. Computationally, the local minima \(\lambda_{\min}\) and maxima \(\lambda_{\max}\) are given...
Fig. 1. Local minima $\lambda_{\text{min}}$ plotted in ‘△’ and local maxima $\lambda_{\text{max}}$ plotted in ‘▽’ of an EEG signal.

Fig. 2. The scalp epileptic EEG (plotted in solid line), and the beginning and the end of epileptic seizure (plotted in dashed line).

$$\lambda_{\text{min}} = \left\{ n = \left\lfloor \frac{s + t}{2} \right\rfloor \mid x[s - 1] > x[n] \text{ and } x[t + 1] > x[n] \right\}$$

and

$$\lambda_{\text{max}} = \left\{ n = \left\lfloor \frac{s + t}{2} \right\rfloor \mid x[s - 1] < x[n] \text{ and } x[t + 1] < x[n] \right\}$$

where $x[s] = x[s+1] = \ldots = x[n] = x[n+1] = \ldots = x[t]$. The local minima and the local maxima of the EEG signal are depicted in Fig. 1.

In this study, the temporal characteristic of EEG signal is measured using the total number of local minima $\lambda_{\text{min}}$ and local maxima $\lambda_{\text{max}}$ that is referred to as the number of local min-max $N_\lambda$.

C. Analytical Framework

The EEG recording chb01_03 was used in this study. This recording is one hour long. Further, only the Fz-Cz channel of the epileptic EEG data was examined. Fig. 2 illustrates the corresponding scalp epileptic EEG signal. In this EEG recording, there is one epileptic seizure event occurs between 2,996 and 3,036 seconds where the dashed lines in Fig. 2 indicate the beginning and the end of the epileptic seizure. In addition, exemplary sections of scalp EEG during a non-seizure period and during an epileptic seizure event are compared in Fig. 3.

The epileptic EEG signal is divided into non-overlapped 10-second epochs. The epileptic EEG epochs are subsequently decomposed into four levels using the discrete Meyer wavelets. There are thus four wavelet subbands: $D_1$, $D_2$, $D_3$ and $A_3$ that correspond to 64–128Hz, 32–64Hz, 16–32Hz and 0–16Hz subbands, respectively. The number of local min-max $N_\lambda$ of the wavelet subbands of epileptic EEG reconstructed from the detail and approximate coefficients is examined. The temporal characteristic of the wavelet subband of epileptic EEG signal as measured using the
number of local min-max $N_\lambda$ is examined by classified into three states of the brain: pre-ictal, ictal and post-ictal states.

### III. RESULTS

The number of local min-max $N_\lambda$ of the $D_1$, $D_2$, $D_3$ and $A_3$ subbands of epileptic EEG signal is illustrated in Fig. 4(a), Fig. 4(b), Fig. 4(c) and Fig. 4(d), respectively. In Fig. 4(a), Fig. 4(b), Fig. 4(c) and Fig. 4(d), the epileptic seizure event is indicated in a shaded area. It is clearly shown that the number of local min-max $N_\lambda$ of epileptic EEG has distinguishable characteristics corresponding to different states of the brain for all four wavelet subbands, i.e., $D_1$, $D_2$, $D_3$ and $A_3$. In particular, note that for the $D_1$ subband the number of local min-max $N_\lambda$ instantaneously increases during the seizure onset while the number of local min-max $N_\lambda$ sharply decreases during the seizure onset for the $A_3$ subband.

Furthermore, when the number of local min-max $N_\lambda$ of the wavelet subbands of epileptic EEG signal is classified into the states of the brain, i.e., pre-ictal, ictal and post-ictal states, the mean, median and standard deviation of the number of local min-max $N_\lambda$ of the wavelet subbands of epileptic EEG signal are summarized in Table I. The number of local min-max $N_\lambda$ of the $D_1$ and $D_3$ subbands of epileptic EEG signal

![Graph](image_url)

**Fig. 3.** Sections of scalp EEG corresponding to different pathological brain states.

![Graph](image_url)

**Table I**

<table>
<thead>
<tr>
<th>Subband</th>
<th>Brain State</th>
<th>Mean</th>
<th>Median</th>
<th>S. D.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$D_1$</td>
<td>pre-ictal</td>
<td>816.70</td>
<td>816.00</td>
<td>7.78</td>
</tr>
<tr>
<td>$D_1$</td>
<td>ictal</td>
<td>857.25</td>
<td>858.00</td>
<td>15.90</td>
</tr>
<tr>
<td>$D_1$</td>
<td>post-ictal</td>
<td>807.75</td>
<td>807.00</td>
<td>6.13</td>
</tr>
<tr>
<td>$D_2$</td>
<td>pre-ictal</td>
<td>413.66</td>
<td>413.00</td>
<td>7.61</td>
</tr>
<tr>
<td>$D_2$</td>
<td>ictal</td>
<td>409.50</td>
<td>410.00</td>
<td>2.52</td>
</tr>
<tr>
<td>$D_2$</td>
<td>post-ictal</td>
<td>394.04</td>
<td>395.00</td>
<td>7.90</td>
</tr>
<tr>
<td>$D_3$</td>
<td>pre-ictal</td>
<td>224.72</td>
<td>225.00</td>
<td>7.14</td>
</tr>
<tr>
<td>$D_3$</td>
<td>ictal</td>
<td>244.00</td>
<td>242.50</td>
<td>8.04</td>
</tr>
<tr>
<td>$D_3$</td>
<td>post-ictal</td>
<td>224.76</td>
<td>224.00</td>
<td>8.83</td>
</tr>
<tr>
<td>$A_3$</td>
<td>pre-ictal</td>
<td>95.53</td>
<td>95.00</td>
<td>10.15</td>
</tr>
<tr>
<td>$A_3$</td>
<td>ictal</td>
<td>57.50</td>
<td>57.50</td>
<td>5.69</td>
</tr>
<tr>
<td>$A_3$</td>
<td>post-ictal</td>
<td>94.33</td>
<td>95.00</td>
<td>9.76</td>
</tr>
</tbody>
</table>
Fig. 4. The characteristics of the number of local min-max of the wavelet subbands of the scalp epileptic EEG associated with different pathological brain states.

during the epileptic seizure event tends to be higher than that associated with other states of the brain. On the contrary, the number of local min-max $N_{\lambda}$ of the $D_2$ and $A_3$ subbands of epileptic EEG signal during the epileptic seizure event tends to be lower than that associated with other states of the brain, i.e., the pre-ictal and post-ictal states.

IV. CONCLUSIONS

In this study, the temporal characteristic of wavelet subbands of the epileptic EEG signal is examined using the feature based on the local minima and maxima. The temporal characteristic is measured using the total number of both local minima and maxima, referred to as the number of local min-max $N_{\lambda}$. From the computational results, it is shown that the epileptic EEG signal has distinguishable characteristics corresponding to different pathological brain states for various wavelet subbands. The most remarkable characteristics of the number of local min-max $N_{\lambda}$ can be observed in the $D_1$ and $A_3$ subbands of epileptic EEG signal.

The number of local min-max $N_{\lambda}$ of the $D_1$ subband of epileptic EEG signal during the epileptic seizure event is significantly higher than that associated with other states of the brain. On the other hand, for the $A_3$ subband the number of local min-max $N_{\lambda}$ of epileptic EEG signal during the epileptic seizure event is significantly lower than that associated with other states of the brain. This implies that during the epileptic seizure event there is an increase of amplitude regularity in the highest frequency components ($D_1$ subband) of epileptic EEG while the amplitude regularity of the lower frequency components ($A_3$ subband) of epileptic EEG decreases.

These computational results suggest that the number of local min-max $N_{\lambda}$ of various wavelet subbands reveals the distinguishing temporal characteristics of the epileptic EEG corresponding to different pathological brain states including ictal state. Therefore, the number of local min-max may be useful in detecting and identifying epileptic seizures from the scalp EEG signal.

REFERENCES


