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Automated Detection of Eeg Spindle Waveforms Based on Its Local Spectrum

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Abstract

A new method of spindle waveform detection is presented for the automated analysis of sleep EEG. The method is based on the combined application of signal conditioning in the time-domain and local spectrum analyzing in the frequency-domain. The overall detection system is implemented and tested in real-time with a total of 24 hour data obtained from four subjects. The result shows an average agreement of 86.7% with the visually inspected result.

1. Introduction

Human electroencephalogram(EEG) exhibits the appearance of various waveforms according to the brain state and the location of electrode placement. Among the waveforms of interest, Alpha, Beta, Sigma, and Theta are classified as spindles in the sense that those generally appear in a form of short-time existing sinusoidal burst. Reliable detection of these spindle waveforms is one of the important tasks for the success of an automated sleep EEG analysis. Considerable successes of the EEG analysis have been reported in several cases of the previous researches[1][2]. However, routine applications of the waveform detection are not yet possible because of the technical difficulties associated with the complex nature and the nonstationary behavior of the EEG characteristics[3].

This paper aims to present a new approach of waveform detection and find out the feasibility of applying a spectral analysis for the purpose of detecting short-time existing EEG waveforms. This contrasts with the conventional frequency-domain approach where spectral characterization of the EEG forms the base of the analysis. Some effective approximations are also suggested for the design and implementation of the signal conditioning filter as well as for the computation of the local spectrum. The presented approach is especially useful for the real-time implementation of a waveform detection system under general purpose microcomputer environment. The detection system is implemented using an Intel 8097 microcontroller system and an IBM type personal computer. The performance of the system is evaluated with the total of 24 hour data obtained from four normal male subjects. The ages of the subjects are between 20 to 30. For each subject, about six hour data are processed in real-time for the evaluation.

2. Detection of Sigma spindle

The Sigma spindle, one of the characteristic waveforms occurring in sleep EEG, shows a shape of sinusoidal burst existing for a relatively short (about 1.0 second) duration. The intra-periodicity of the spindle is in the range of 12~16 Hz. Therefore, a windowed spectrum of the spindle, if the window length is appropriately chosen, shows a mainlobe peak within the frequency range 12~16Hz. The detection of this mainlobe is the key idea of the suggested detection method.

Signal conditioning is important for the correct shaping of the mainlobes by removing background activities and noises. Capitalizing on the fact that a filter with a relatively wide bandwidth and a smooth transition

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characteristic is appropriate for the conditioning purpose, a linear phase FIR filter of a special type is designed as is described in [2]. A desired bandpass filter can be obtained from a comb filter by suppressing unnecessary arcades with the addition of complex conjugate zeroes between the arcades. Allowing some approximations in the location of the inserted zeroes, the filter can be implemented using only a limited number of shift and add instructions. The equation of the filter designed for the Sigma spindle conditioning is,

$$H(z) = (z^{-5} - 1)(z^{-2} + 1.5z^{-1} + 1)(z^{-1} + 1).$$

Examples of the filtering effects are illustrate in Fig. 1. It is shown that the effect of large amplitude wave and high frequency noise is removed while the shape of the spindle is enhanced.

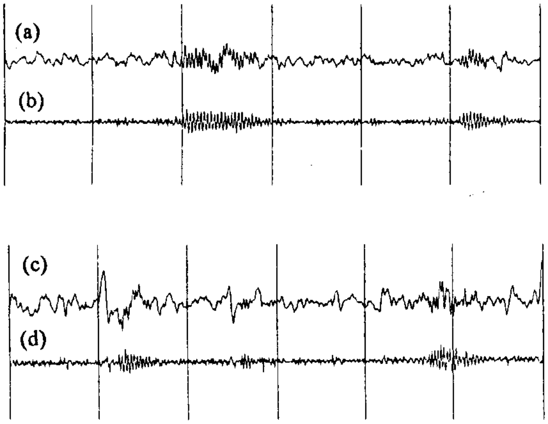

Fig. 1. Illustrations of the signal conditioning. (a) Original signal which contains Sigma spindles. (b) Filtered output to the input (a). (c) Original signal which contains large amlituse Delta waves. (d) Filtered output to the input (c).

The frequency resolution of the detection and the complexity of the implementation are the important design considerations in determining the values of the design parameters. In case of N-point DFT, $2\pi / N$ becomes the frequency resolution, Δf. The resolution must be sufficiently shorter than the mainlobe width, Bw, in order not to miss the peak in the detection. Increasing the number of DFT point N, on the other hand, calls for the implementation complexity.

EEG channels are sampled at the rate of 240 Hz with a 10 bit A/D conversion. After the signal is conditioned by the filtering, it is further decimated by 2:1 subsampling. The final sampling rate, f_s becomes 120 Hz. The window length, T is selected as two seconds considering the length of the spindle. Therefore, the local spectrum is obtained by computing 256-point DFT (Discrete Fourier Transform) of two second data with the zero-padding of 16 points at the end.

With the design chosen in the above procedure, the detection level becomes always higher than 64.7% of the mainlobe peak as is illustrated in Fig. 2., since,

$$\Delta f = 120/256 \approx 0.47 \text{ and,}$$

$$\frac{\sin(\pi \frac{\Delta f}{2} T)}{\pi \frac{\Delta f}{2} T} = \frac{\sin(\pi \times \frac{0.47}{2} \times 2)}{\pi \times \frac{0.47}{2} \times 2} \approx 0.674.$$

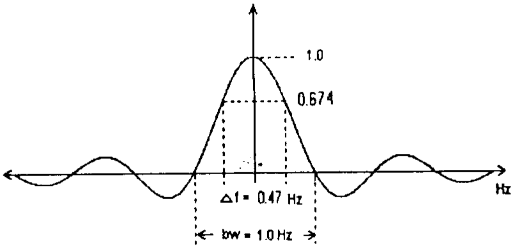

Figure 2. Shape of the mainlobe for a windowed Sigma spindle.

Computation of the N-point DFT requires the multiplications with the N pairs of the coefficients, i.e., $\cos(\frac{2\pi nk}{N})$, $\sin(\frac{2\pi nk}{N})$ for $k = 0 \sim N-1$. In contrast to the quantitative spectral analysis where numerical precision of the computation is important, the waveform detection does not require high precision in numeric computation as long as the detection performance is not significantly deteriorated. The computation can be significantly reduced if the amount of approximation is maximized. The coefficients are approximated using five-bit precision and stored in a table so that the computation can be performed by a limited number of shift and add instructions. The contour of the approximated coefficients are illustrated on the z-plane as shown in Fig. 3.

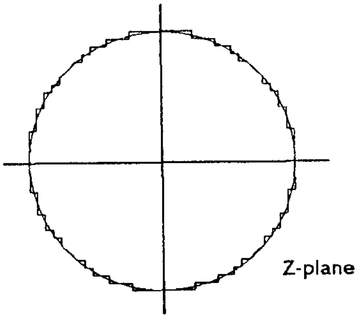

Fig. 3. Contour of the approximated coefficients with 5-bit precision on the z-plane.

The DFT need not be computed for all the frequency components. Only the frequency components in the range 12~16 Hz, i.e., X(26)~X(34) need to be computed and checked to see if the magnitude exceeds the threshold level, which is currently set at 25% of the peak. In order to take care the case where the sigma spindle is splitted by the window, overlapping of one second is introduced in the windowing.

3. Implementation of the System

The overall detection system is implemented using a multiple processor structure composed of an Intel-8096 based front-end system and an Intel-80386 based host computer. The front-end processor includes the routines for the A/D conversion, the signal conditioning, and the waveform detection. The host computer stores the digitized raw data and interfaces to the operator. The overall system structure of the detection system is shown in Fig. 4. EEG signals are picked up by the electrodes and amplified by the EEG machine. The amplified signals are digitized by the A/D converter of the front-end processor. The system also includes the calibration and other interfacing circuits.

The front-end processor is implemented based on the Intel 8097 16 bit microcontroller. The processor possesses the appropriate features, including the 10 bit A/D converter, PWM D/A, timer, counter, etc., for the purpose of real-time implementation of the waveform detection system. The communication between the host computer and the front-end processor is performed by the RS232 serial communication with 19,200 bps. The PWM output is filtered by the cascaded low-pass filter which has the 3-dB cutoff frequency at 230 Hz. The binary pulse type signal is output through the parallel port of the processor and recorded on the polygraph-chart paper together with the raw EEG signals.

The overall software of the detection system consists of a main routine which performs the waveform detection, an interrupt handler routine which performs the A/D conversion and filtering, and the host program which performs the data acquisition and the handling of the communication with the front-end processor.

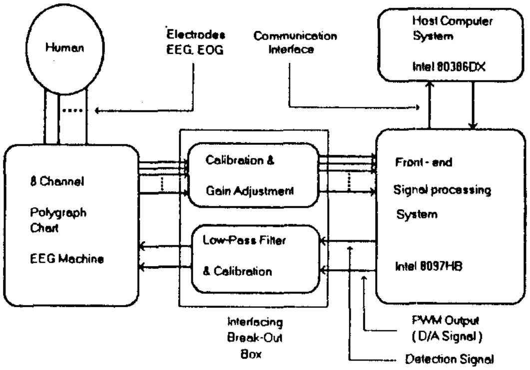

Fig. 4. Overall structure of the detection system.

4. Experiments and Results

Three channels of EEG (Fp1-F7, C3-A2, O1-Pz) and one channel of EOG (LE-A2), according to the International 10-20 electrode placement system, are acquired and processed by the designed system in real-time. The signals are also simultaneously recorded on the EEG paper by an eight-channel EEG machine. The central channel EEG is used for the Sigma spindle detection. The detected output is also marked on the paper so that it can be compared with the visually inspected result. Examples of the Sigma spindle detections are illustrated in Fig. 5, where the detection result is recorded on the polygraph-chart in real-time together with the EEG signal.

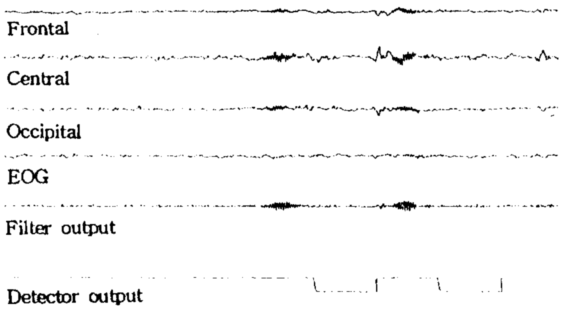

Fig. 5. Illustration of the Sigma spindle detection recorded on the polygraph-chart in real time by the front-end waveform detection system.

Four normal male subjects are selected for the experimental evaluation of the waveform detection system. All the subjects are in 20s. A total of 24 hour data, one night for each subject, are processed. The recorded paper is also visually inspected for the Sigma spindle detection. The comparison result is summarized in the table 1, where the detection ratio (DT) and the false detection on ratio(FDR) are defined as,

$$\mathrm{DR} = \frac{\text{agreed detection}}{\text{visual detection}} \times 100\ [\%] \text{ and,}$$

$$\mathrm{FDR} = \frac{\text{system detection - agreed detection}}{\text{visual detection}} \times 100[\%].$$

Table 1. Summary of the detection results analyzed by the system and by the visual inspection

Subject	Visual detection [#]	System detection [#]	Agreed detection [#]	Detection ratio [%]	False detection ratio [%]
1	568	689	520	91.5	29.8
2	664	728	586	88.3	21.4
3	1254	1403	1110	88.5	23.4
4	548	534	413	75.4	22.1
Total	3034	3354	2629	86.7	23.4

The average detection ratio is 86.7% and the false detection ratio is 23.9 %. Considering that the required agreement rate of a qualified visual inspector is 90%, the agreement rate of the system can be regarded as satisfactory. Noting that human visual inspection also provides poor agreement for the portion of the record which is dominated by Delta activities [2], the agreement of the system will become higher than 90% if such Delta dominated portion of the record is excluded from the statistics.

4. Conclusion

It is shown that the spindle waveforms can be detected by checking the existence of a salient mainlobe in the local spectrum of pre-conditioned EEG. The approximations utilized in the filter design and the DFT computations are especially useful for the implementation of a real-time system under general purpose microcomputer environment. The presented approach shows a certain level of feasibility by an experimental evaluation. However, further studies are required including the elaboration of the detection algorithm including tests with a wide range of subjects, before a firm conclusion about the feasibility of the presented approach is made.

References

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