Signal Conditioning Filters for EEG Waveforms Detection

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This paper investigates the EEG waveform distortions caused by the transient responses of the various types of signal conditioning filters, which are generally introduced for the automated EEG analysis. This study explicitly simulates the filter responses to the typical EEG waveform models, and compares the distortions.

1. INTRODUCTION

EEG waveforms detection is believed to form the core part of the human EEGer's visual inspection process. Therefore, the establishment of a correct set of the waveform criteria is crucial for the success of the automated EEG analysis. Most of the EEG waveforms are short-time existing sinusoidal bursts. Waveforms of this type are generally called as "spindles" and further distinguished as alpha, beta, theta and sigma, according to their intra-waveform periodicities. Some of the EEG aveforms such as delta are described by the half-wave periodicity. A set of waveform definitions including the periodicity windows are available in [1][2].

The EEG waveforms are always superimposed on the background noise activity. Therefore, some type of signal conditioning filters are invariably involved in the processing. The purpose of the filters is to remove unwanted frequency component (or noises in a more general term) and to enhance the desired frequency component of interest from the signal. Besides the involvement of the signal conditioning filters in the analysis, various other types of filters are often introduced in the data acquisition procedure. The AC coupled recording of EEG machine is an example of the introduction of a highpass filter. The AC coupling is to reject the high potential DC voltage. A notch filter is often included in the machine to reject the power line interference.

It must be stressed that the filters not only remove the unwanted component of the signal but also distort the signals of interest (waveforms). Especially, since the EEG waveforms are short-time existing transient phenomena, the filter transient response may significantly distort the waveform shapes. In this paper, the effects of the transient responses of various types of filters are investigated by explicitly simulating the filter responses to the typical EEG waveforms, i.e., the sigma spindle and the delta wave.

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2. FILTER TRANSIENT RESPONSES

Various types of bandpass filters are designed and the effects of the filter transients are investigated with the sigma spindle waveform model, i.e., a 13.5 Hz sinusoidal burst with 0.5 seconds of duration. A full cycle of 0.5 Hz sinusoidal wave is used to investigate the effect of the filter transients to the delta wave.

The 2nd-order and the 4th-order Butterworth bandpass filters are designed with the narrow bandwidth (12 - 16 Hz) specification. This bandwidth conforms that of the intra-sigma spindle periodicity [2]. The 2nd-order and the 4th-order Butterworth bandpass filters are also designed with the wider bandwidth (12 Hz - 36 Hz) specification. To investigate the delta wave distortion, the 2nd-order Butterworth bandpass filters are also designed with the two different bandwidth specifications; 0.1 - 2.0 Hz and 0.1 - 10.0 Hz. The designed analog filters are transformed to the digital counterpart filters by using the bilinear transform technique[3]. The sampling frequencies of the digital filters are 240 Hz for the sigma conditioning filters and 70 Hz for the delta conditioning filters, respectively.

The effect of the transient response of the FIR linear phase filter which is designed for the sigma spindle conditioning filter in the automated EEG analysis [2] is also compared with those of the other IIR filters.

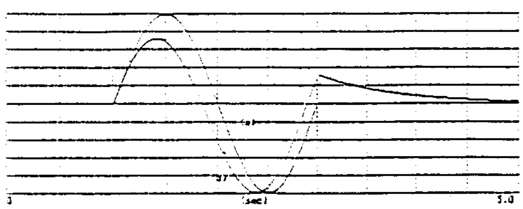

Fig.1. Output of the 2nd-order Buttetworth filter(0.1 - 10 Hz). (a) 0.5 Hz sinusoidal input. (b) output of the filter.

3. EXPERIMENTS AND RESULTS

In Fig. 1, the response of the 2nd-order Butterworth filter to a full period of 0.5 Hz sinusoidal wave is illustrated. The delta conditioning filter shows the significant amount of waveform distortions. The half wave shows the reduction of 28% in its peak amplitude level and the reduction of 16% in its half-wave period.

The Fig.2 shows the outputs of three different types of the filters to the input signal of 13.5 Hz sinusoidal burst. As is illustrated, the distortion gets bigger as the order of the filter is increased.

The narrowband 4th-order Butterworth filter shows the worst distortion. In this case, the first peak of the output is reduced to only about 5% of the input peak. More than 5% of the reduction is still shown at the 7th half-wave peak. The wideband filters show the less distortions compared to the narrowband filters. The linear phase FIR filter shows the smallest distortion. The first peak of the output shows about 38% amplitude reduction and there does not exist any further amplitude distortion from the second peak. The filter magnitude distortions are summarized and shown in the Fig.3.

4. DISCUSSIONS AND CONCLUSION

The distortions resulting from the effects of the transient responses of the various types of the filters are investigated by explicitly simulating the filter responses to the typical EEG waveforms, i.e., the sigma spindle and the delta wave. It is illustrated that the signal conditioning filters generally produce the amplitude and period distortions because of the transient responses of the filters. The filters with wider bandwidth generally produce less waveform distortion and the lower order filters give less distortion compared to the higher order filters. The linear phase FIR filters are generally more robust to the waveform distortion. Such an explicit analysis of the waveform distortions can provide a very much useful information for the definition of the waveforms criteria as well as for the design of signal conditioning filters needed for the automated analysis of EEG data.

REFERENCES

[1] J.R. Smith, Automated Analysis of Sleep EEG Data, Handbook of Electroencephalgraphy and Clinical Neurophysology, Vol. 2, Elsevier Science Publishing Co., Inc., New York 1986, 131-147.

[2] T.G. Chang, J.R. Smith, and J.C. Principe, "An Expert System for Multichannel sleep EEG/EOG signal analysis," ISA Transactions, Vol. 28, No.1, 1989, pp.45-51

[3] A.V. Oppenheim and R.W. Schafer, Digital Signal Processing, Prentice-Hall Inc., 1975.

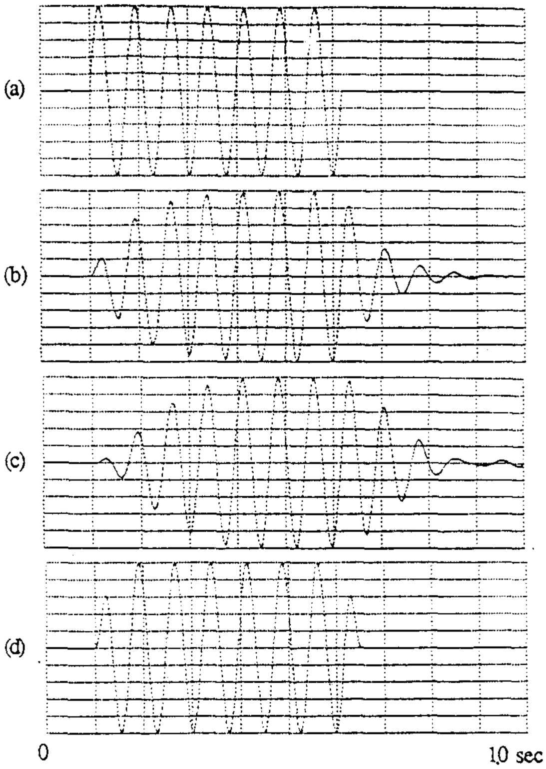

Fig.2. Outputs of the filter to the 13.5Hz sinusoidal burst. (a) 13.5Hz sinusodal burst (12 - 16 Hz) (b) 2nd-order Butterworth filter output (c) 4th- order butterworth filter(12 - 16 Hz)output (d)liner phase FIR filter (12 - 36 Hz) output.

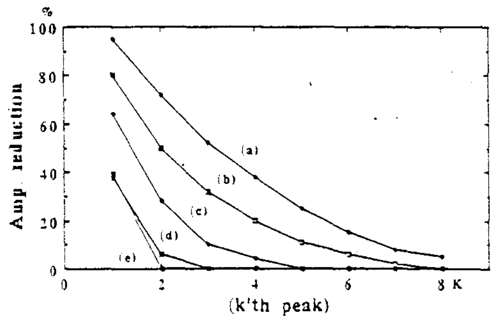

Fig.3. Summary of distortions interms of peak amplitude reduction. (a) 4th-order Butterworth filter (12 - 16 Hz) (b) 2nd - order Butterworth filter (12 - 16 Hz) (c) 4th-order Butterworth filter (12 - 36 Hz) (d) 2nd - order Butterworth (12 - 36 Hz) (e) liner phase FIR filter