A NEAR-OPTIMUM FILTER FOR SUPPRESSING MOTION ARTIFACT IN OSCILLOMETRIC SIGNALS

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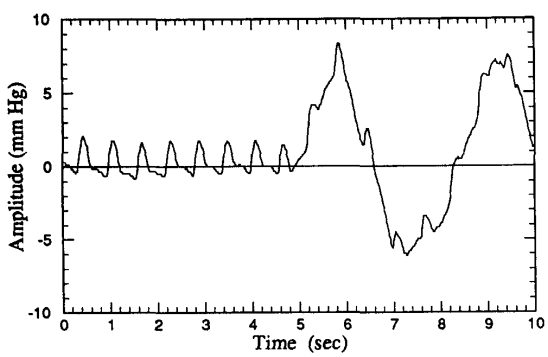
ABSTRACT

Adaptive tourniquets have been designed which estimate the minimum limb-occluding pressure of the tourniquet cuff by oscillometry. A near-optimum motion artifact filter is presented which permits these oscillometric occlusion pressure determinations to be performed under conditions of moderate surgical limb manipulation, which has previously not been possible.

INTRODUCTION

Adaptive pneumatic surgical tourniquets [1], [2] have been developed which use a cuff with a proximal sensor bladder to repetitively estimate, via oscillometry [3], the minimum limb-occluding pressure (MLOP) of a distal occlusive bladder. During surgery, however, passive limb manipulation corrupts the signal from the sensor bladder with low frequency additive noise (Fig. 1), thus reducing accuracy of the MLOP estimate and significantly extending measurement time by requiring the suspension of analysis until motion artifact ceases.

A new adaptive tourniquet [4] achieves improved MLOP estimation performance during periods of moderate limb manipulation through use of a single, near-optimum analog filter in conjunction with an adaptive pulse pattern recognition algorithm. This paper outlines the development of the filter and will compare its signal to noise ratio (SNR) performance to that achieved by patient-specific optimum digital filters.



by limb

EXPERIMENT AND SIGNAL ANALYSIS

Oscillometric pulse and motion artifact noise signals, observed at constant baseline pressure, were obtained with the sensor bladder of an adaptive tourniquet cuff from the arms and legs of 11 normotensive male and female volunteers using the protocol described in [4]. Signal acquisition was performed with an 8-bit A-D converter over a bandwidth of 0.1 - 50 Hz at a sampling rate of 200 Hz.

From the uncorrupted signal data, individual pulses were extracted and multiplied by a Kaiser-Bessel window [5], after which the spectrum was computed by fast Fourier transformation. Each noise signal was multiplied by a similar window, and the power spectral density obtained by FFT as well. Selective linear prediction [6] was used to model, via solution of the Yule-Walker equations, the ensemble average of all noise PSD's as a 4th order autoregressive process driven by white noise over a 20 Hz bandwidth (Fig. 2).

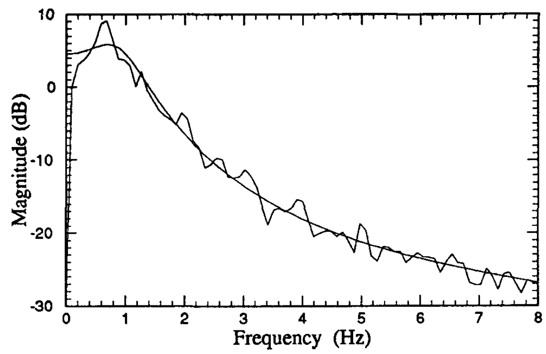


Figure 2. *Ensemble average of noise spectra and 4th order AR PSD model.*

FILTER DESIGN

The optimum filter which maximizes SNR is well known [7], and in this case could be digitally implemented as the inverse filter of the motion artifact AR PSD model, which would whiten the noise spectrum, followed by the matched filter of a whitened oscillometric pulse. Use of a matched filter implies that this optimum processor would have to be uniquely determined for each patient. This was deemed undesirable, and an alternative near-optimum filtering scheme was sought.

CH2770-6/89/0000-0640 $01.00 C 1989 IEEE

Each oscillometric pulse spectrum, the motion artifact PSD estimate, and seven IIR high pass filters with cutoff frequencies ranging from 0.2 to 7.8 Hz in 0.2 Hz steps were used in an exhaustive series of discrete frequency domain SNR calculations. The SNR degradation was defined as the ratio of the SNR achieved after high pass filtering to that obtained by the optimum filter for a given oscillometric pulse spectrum. Figure 3 shows the mean degradation obtained at each cutoff frequency for a single RC section, a 3rd order Bessel filter, and a 4th order Butterworth filter. The lowest mean degradation of -2.8 dB was achieved by the 3rd order Bessel filter with a cutoff frequency of 3.6 Hz. This corresponds to a mean output SNR of +8.6 dB.

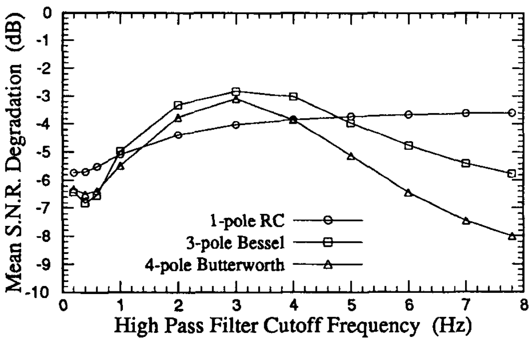


Figure 3. *Mean degradation from optimal SNR after analog high pass filtering.*

Figure 4 compares the output of the optimum digital filter to the output of the Bessel filter realized with active filter sections for a motion-corrupted input signal. The Bessel filter is followed by a Butterworth low pass filter with cutoff equal to 8 Hz, which is greater than the 99.5% energy bandwidth of all signals used in this study. Note the similarity in output waveforms and the practically equivalent improvement in SNR.

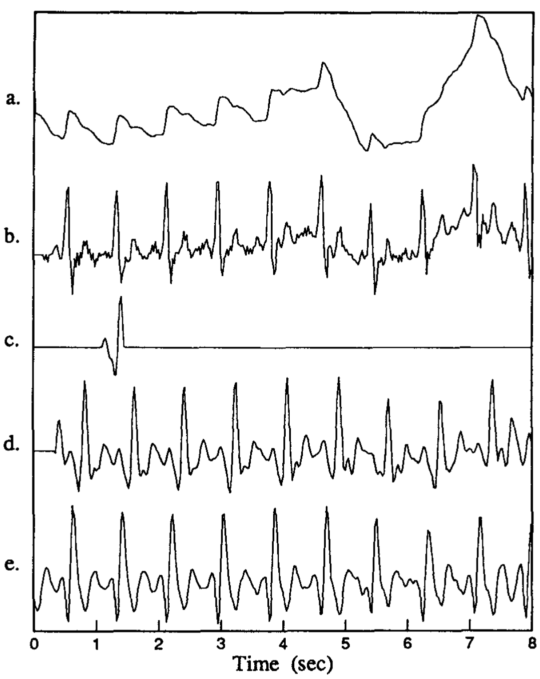


Figure 4. *(a) motion-corrupted input; (b) output of inverse filter; (c) matched filter; (d) optimum filter output: convolution of (b) & (c); (e) output of analog filter (arbitrary y scales).*

CONCLUSION

These experiments have shown that for the oscillometric signals studied, the patient-specific optimum filter can be replaced by a single analog filter with little degradation in motion artifact suppression. Oscillometric limb occlusion pressure measurements have been successfully performed under conditions of moderate surgical limb manipulation using the filter in conjunction with an adaptive pulse pattern recognition algorithm.

REFERENCES

[1] J.A. McEwen and R.W. McGraw, "An adaptive tourniquet for improved safety in surgery", *IEEE Trans. Biomed. Eng.* Vol. BME-29, pp. 122-128: Feb. 1982.

[2] C.R. Bussani and J.A. McEwen, "Improved tracking of limb occlusion pressure for surgical tourniquets", *IEEE Trans. Biomed. Eng.* Vol. BME-35, pp. 221-229: Apr. 1988.

[3] L.A. Geddes, "Blood pressure: Non-invasive measurement", in *Cardiovascular Devices and Their Applications*. New York: Wiley & Sons, 1984, pp. 67-72.

[4] M.E. Miller, "A high performance adaptive tourniquet system for orthopaedic surgery", M.A.Sc. Thesis, University of British Columbia, Vancouver, Canada, 1989.

[5] F.J. Harris, "On the use of windows for harmonic analysis with the discrete Fourier transform", *Proc. IEEE* Vol. 66, pp. 51-83: Jan. 1978.

[6] J. Makhoul, "Linear prediction: A tutorial review", *Proc. IEEE* Vol. 63, pp. 561-580: Apr. 1975.

[7] M.Schwartz, *Information Transmission, Modulation, and Noise.* New York: McGraw-Hill, 1970, pp. 410-421.

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