ENHANCEMENT OF RADIAL ARTERIAL PULSE BY SPECTRAL SUBTRACTION

Aparna M. Surve
EE Dept., IIT Bombay
Powai, Mumbai 400 076, India
(+91-22) 2576 4417
aparnas@ee.iitb.ac.in

Prem C. Pandey
S.S. Pratapwar
EE Dept., IIT Bombay
Powai, Mumbai 400 076, India
(+91-22) 2576 7445
pcpandey@ee.iitb.ac.in
santosh@ee.iitb.ac.in

Vinod K. Pandey
N.S. Manigandan
Bio School, IIT Bombay
Powai, Mumbai 400 076, India
(+91-22) 2576 4417
vinod@ee.iitb.ac.in
manigandanns@iitb.ac.in

ABSTRACT

Noninvasive recording of pressure pulse waveform from the radial artery can be used for obtaining valuable diagnostic information, by analyzing it for temporal characteristics, spectral characteristics, and its cross-correlation with phonocardiogram and ECG. The pulse waveform can be recorded using the transducer of an electronic stethoscope, but the signal is corrupted by noise. We have investigated the use of spectral subtraction method, reported earlier for enhancement of noisy speech, for noise reduction in the pulse waveform. Enhancement can be carried out by taking the noise recording from a nearby site, or by using a quantile based spectral estimate of noise from the noisy pulse waveform.

Keywords

Signal enhancement, radial arterial pulse, spectral subtraction.

1. INTRODUCTION

In most traditional systems of medicine, e.g. *nadisastra* (a branch of *ayurveda*, ancient and well established medical system of India), sensing of arterial pulse pressure forms an essential part of diagnosis. Normally physician's palm supports the patient's wrist and pulse examination is done using finger tips [11]. The diagnosis requires a long period of study and practice by the individual physician, without the benefit of any physical recordings and analysis aids. Lately several investigations have been reported on noninvasive recording and analysis of arterial pressure pulse waveform [3,5,7].

Paper Identification Number: CI-1.7

Analysis of the waveform for its temporal and spectral characteristics can give valuable diagnostic information, particularly when used together with electrocardiogram (ECG) and phonocardiogram (PCG). Cross-correlation of arterial pulse with ECG and PCG waveforms may provide important diagnostic information about arterial blood flow.

Early studies on pulse waveform have used Dudgeon's sphygmograph [6,11]. Its use involved a tedious process of preparation of tracings and measurements from the tracings. Further, it had other limitations like poor dynamic response. Several instruments have been developed and reported for sensing the pulse waveform and giving the output as electrical analog voltage or as digitized samples and built-in analysis [1,3,5,7]. The arterial tonometer is one such instrument for acquisition of beat-to-beat blood pressure waveform along with numerical values for systolic, mean, diastolic pressure and pulse rate [1].

The pulse waveform can be recorded using the transducer of an electronic stethoscope or phonocardiograph. The main advantage of this technique is a good dynamic response. But the signal is corrupted by noise, environmental sounds as well as the vibrations from various smaller blood vessels. As the noise has essentially the same band as the signal, it cannot be reduced by filtering techniques. We have investigated the use of spectral subtraction method, reported earlier for enhancement of noisy speech, for noise reduction in the pulse waveform. For this purpose, estimate of noise spectrum can be obtained using noise recording from a nearby site or by using a quantile based spectral estimate of noise from the noisy pulse waveform itself.

2. SPECTRAL SUBTRACTION ALGORITHM

The basic assumption in spectral subtraction method [2,4,8], developed for enhancement of speech corrupted by noise, is that the clean signal and the noise are uncorrelated, and therefore the power spectrum of noisy signal equals the sum of power spectrum of noise and clean signal. Let $x(n)$ be the windowed noisy signal comprising of the clean signal $s(n)$ and the additive noise $l(n)$,

$$x(n) = s(n) + l(n) \qquad (1)$$

Taking short-time Fourier transform on both sides, we get

$$X_n\left(e^{jw}\right) = S_n\left(e^{jw}\right) + L_n\left(e^{jw}\right) \quad (2)$$

Assuming $s(n)$ and $l(n)$ to be uncorrelated, we get

$$\left|X_n\left(e^{jw}\right)\right|^2 = \left|S_n\left(e^{jw}\right)\right|^2 + \left|L_n\left(e^{jw}\right)\right|^2 \quad (3)$$

The basic spectral subtraction algorithm works in two steps: (i) noise spectrum is estimated and (ii) the estimated noise spectrum is subtracted from that of the noisy signal to get

$$\left|Y_n\left(e^{jw}\right)\right|^2 = \left|X_n\left(e^{jw}\right)\right|^2 - \left|L_n\left(e^{jw}\right)\right|^2 \quad (4)$$

The resulting magnitude spectrum is then combined with the original phase spectrum to resynthesize the "cleaned" signal. Using FFT for implementation, the steps can be written as

$$|Y_n(k)|^2 = |X_n(k)|^2 - |L(k)|^2 \quad (5)$$

$$y_n(m) = IFFT\left[|Y_n(k)|e^{j\angle X_n(k)}\right] \quad (6)$$

When the estimate of the noise spectrum is subtracted from the actual noise spectrum, all the spectral peaks are shifted down while the points lower than the estimate are set to zero. Hence, after subtraction, noise spectrum is obtained with peaks. The wider peaks are considered as a broadband noise and the narrower peaks are considered as the musical noise. Thus the spectral subtraction method is modified for minimizing this noise [2].

$$|Y_n(k)|^2 = |X_n(k)|^2 - \alpha|L(k)|^2$$

$$|Y'_n(k)|^2 = |Y_n(k)|^2 \qquad \text{if } |Y_n(k)|^2 > \beta|L(k)|^2$$

$$= \beta|L(k)|^2 \qquad \text{otherwise} \quad (7)$$

where α is the subtraction factor and β is the spectral floor factor.

A block diagram of the modified spectral subtraction algorithm is shown in Figure 1.

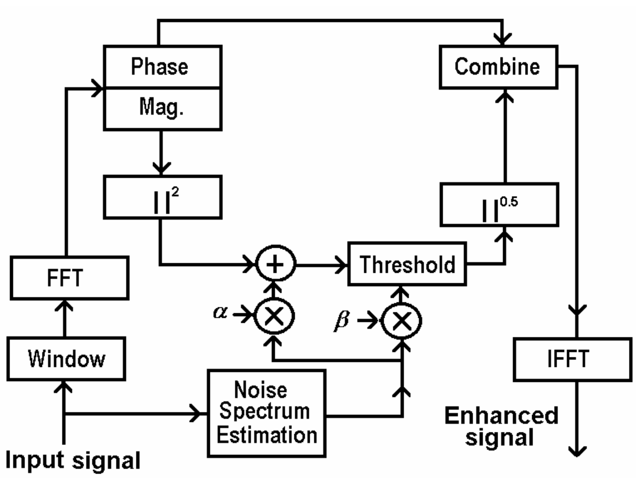


Figure 1: Spectral subtraction algorithm [8].

With α > 1, the noise will be over subtracted from the noisy signal. However over subtraction increases signal distortion. This is taken care by the spectral floor factor β. The spectral components of $|Y'_n(k)|^2$ are prevented from going below $\beta|L(k)|^2$. The implementation via FFT requires overlap-and-add in order to prevent discontinuities at frame boundaries [2].

For enhancement of noisy speech signal, a speech / non-speech detection is used for updating the noise estimate. In case of arterial pressure pulse waveform, the signal and corrupting noise both are always present. Assuming that the noise is stationary, its average spectrum can be estimated from the noise recorded from a nearby site, which does not show the pulse waveform. Recently, techniques for speech enhancement without involving speech / nonspeech detection have been reported [9,10]. These are based on quantile analysis of the signal spectrum. This method can be used for noise estimation for enhancement of pulse waveform for dynamic tracking of variations in noise spectrum.

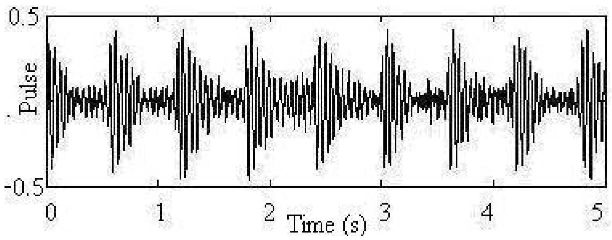
3. NOISE ESTIMATION

The pulse waveforms were recorded by keeping PCG sensor over radial artery on the wrist and adjusting the position for strongest signal pick up. The noise was acquired by keeping the sensor on the same hand but away from the radial artery at two different locations. The waveforms were acquired using PC sound card with a sampling rate of 1.1,025 k sa/s (11.025 k Sa/s, followed by 10:1 decimation). The averaged noise spectrum was computed over a record of 16 s, using a 1.6 s window with 50% overlap. This averaged power spectrum is used for spectral subtraction.

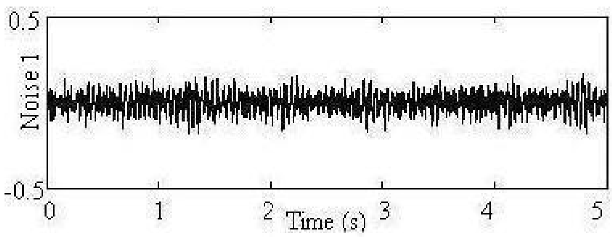
In the above method, the noise spectrum is taken to be constant over the entire duration of the signal to be enhanced. An updated estimate of noise spectrum can be obtained by use of quantile-based noise estimation (QBNE) technique [9,10]. It is based on the assumption that frequency bins in the signal spectrum tend not to be permanently occupied. The noisy pulse signal is analyzed on a frame-by-frame basis, to obtain an array of the power spectral values for each frequency sample, for a certain number of frames. Then the magnitude-squared values in this array are sorted for obtaining a particular quantile value. The power spectrum of noisy pulse at different quantile values is compared with the mean power spectrum of noise recorded from the nearby site for obtaining the quantiles in frequency bands for matching the two spectra.

4. RESULTS

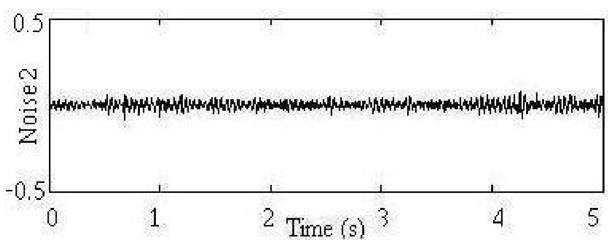
Spectral subtraction algorithm was used for enhancement of radial arterial pulse obtained from the analog electrical output of an electonic stethoscope (Stethmate). The effect of noise recorded at several sites on the same hand was studied. Fig. 2 shows the noisy pulse waveform and noise obtained at two different locations on hand. Spectral subtraction was carried out with β=0.001 and varying α over 0.5 to 5. It was seen that lower values of α did not result in good noise subtraction, while larger values resulted in over-subtraction and a reduction in pulse peaks. Fig.3 shows an example of pulse waveform after spectral subtraction.



(a)



(b)



(c)

Figure 2: Pulse pressure waveform: (a) noisy pulse waveform (b) noise at location 1 (c) noise at location 2.

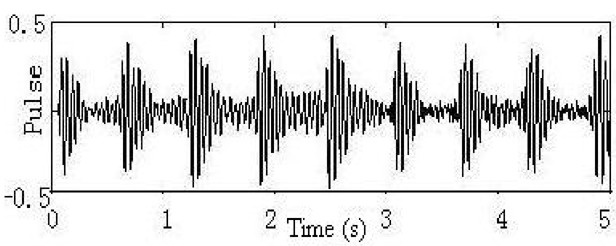
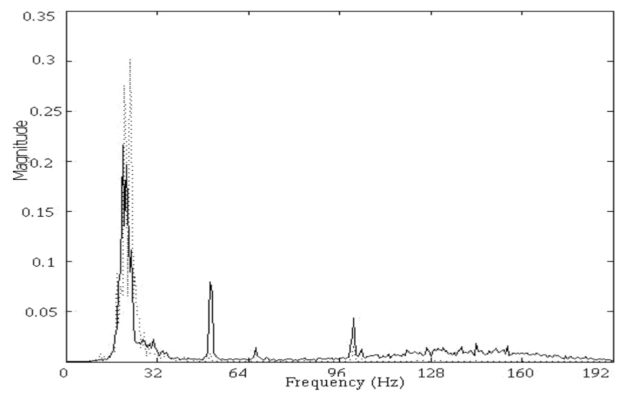


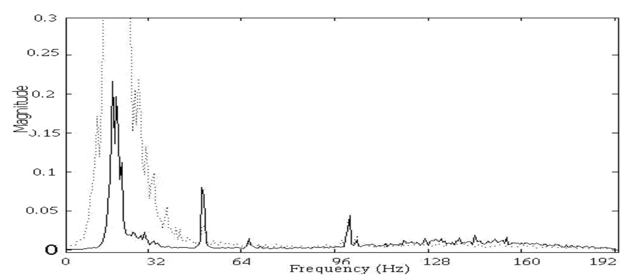
Figure 3: Enhanced pulse waveform by using noise estimation from noise recorded at location 1, using α =2.

For QBNE, the averaged spectrum of noise from the nearby site was compared with the spectrum of noisy pulse at different quantile values to obtain set of quantile values for giving a close match. It was observed that a good match could be obtained for 5 percentile for frequencies less than 32 Hz and 70 percentile for higher frequencies. Fig. 4 shows the averaged spectrum of noise and two quantile based estimates. Fig. 5 shows an example of pulse waveform enhanced using QBNE spectrum.

It was seen that the value of α and the type of noise estimate both have significant effect on noise reduction as well as over-subtraction. As an estimate of the two, the RMS value of the overall signal and the RMS value of the signal samples in the vicinity of the pulse peaks were calculated. Fig. 6 shows a plot of these RMS values as function of α for the two types of noise estimates. It is seen that for averaged noise estimate, both the RMS values decrease with increasing α. For QBNE spectrum, the noise estimation is much more effective. For $\alpha > 2$, the peak RMS decreases without any further decrease in signal RMS. Hence we can say that, we get the best signal enhancement by using QBNE spectrum for $\alpha \approx 2$.



(a)



(b)

Figure 4: Averaged noise spectrum and QBNE spectrum for (a) 5 percentile and (b) 70 percentile. Plot with solid line shows the average power spectrum of noise and the plot with dotted line shows the quantile derived spectrum of noisy pulse.

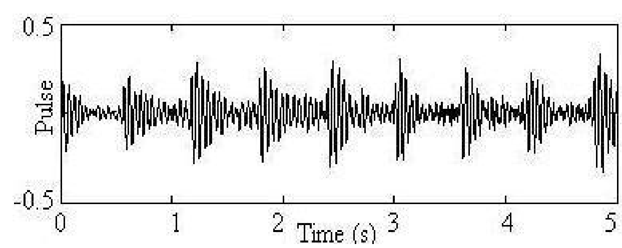
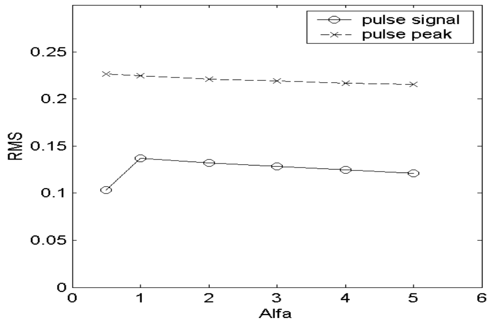
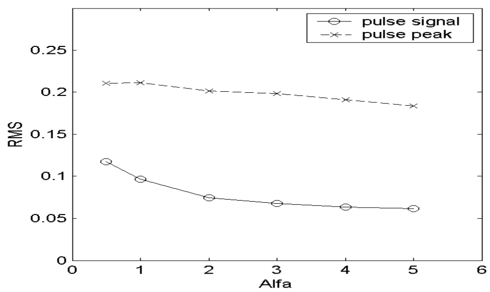


Figure 5: Enhanced pulse waveform by using noise estimation from noisy pulse using QBNE, using α =2.



(a)



(b)

Figure 6: Effect of α on reduction of noise and peak (a) with averaged noise spectrum and (b) with QBNE.

5. CONCLUSION

Spectral subtraction, reported earlier for enhancement of noisy speech, has been investigated for enhancement of arterial pulse pressure waveform recorded using PCG transducer. It is seen that a quantile based estimation of the noise spectrum from the noisy pulse itself can be used. We are carrying out further study of cross-correlation of the enhanced pulse waveform with simultaneously recorded PCG and ECG waveforms, for possible diagnostic applications.

6. REFERENCES

[1] Arterial Tonometry, http://www.colin- europe.com/pages/ tonometry.html, (2002).

[2] Berouti, M., Schwartz, R., and Makhoul, J. Enhancement of speech corrupted by acoustic noise. In Proc. ICASSP ’79, (1979), 208-211.

[3] Binghe, W., and Jinglin, X. Detecting system and power spectral analysis of pulse signals. In Proc. of ICSP '98, (1998), 1646-1649.

[4] Boll, S. F. Suppression of acoustic noise in speech using spectral subtraction. IEEE Trans. ASSP, 27, 2, (1979), 113-120.

[5] Dasrao, M. S., Hock, Y. J., Sim, E. K. W. Diagnostic blood pressure wave analysis and ambulatory monitoring using a novel non-invasive portable device. In Proc. Int. Conf. Biomedical Engineering Biovision 2001, (Bangalore, 2001), 267-272.

[6] Dudgeon's sphygmograph, http://www.uihealthcare.com/ depts/medmuseum/galleryexhibits/beatgeohistory/ 02bloodpressue.html, (2001).

[7] Lee, C., and Wei, L. Spectrum analysis of human pulse. IEEE Trans. Biomedical Engineering, 30, (1983), 348-352.

[8] Pandey, P. C., Bhandarkar, S. M., Bachher, G. K., and Lehana, P. K. Enhancement of alaryngeal speech using spectral subtraction. In Proc. 14th Int. Conf. on Digital Signal Processing DSP 2002, (Santorini, Greece, 2002), 591-594.

[9] Pratapwar, S. S., Pandey, P. C., and Lehana, P. K. Reduction of background noise in alaryngeal speech using spectral subtraction with quantile based noise estimation. In Proc. of 7th World Multiconference on Systemics, Cybernetics and Informatics SCI, (Orlando, USA, 2003).

[10] Stahl, V., Fischer, A., and Bippus, R. Quantile based noise estimation for spectral subtraction and Wiener filtering. In Proc. ICASSP '00, (2000), 1875-1878.

[11] Upadhyay, S. Nadi Vijnana : Ancient Pulse Science. Chaukhamba Sanskrit Series, Varanasi, 1986.