Simple Detector Of Pulse Wave Beats

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Abstract: Various methods for detecting the fiducial points of the pulse wave signals are discussed. A new simple detector of the fiducial points based on the application of the first derivative operator, set of nonlinear transformations and adaptive threshold is described. The efficiency of various detectors of the beat points of pulse wave signal in the presence of interferences of various origins and intensities was estimated. It is demonstrated that the suggested detector provides the minimum level of uncertainty in the determining time position of pulse wave beats.One of the possible ways to investigate the effectiveness of detecting pulse wave beats is to model these processes for the studied biosignal and the contaminated factors. The mathematical model of pulse wave signal with presented noise caused by motion artifacts and baseline wander is assumed to be additive.Thus, among the considered detectors of pulse wave beats in this work, the proposed amplitude–time detector based on first derivative, set of nonlinear operators and adaptive threshold provides better efficiency and accuracy of detection.

Keywords: pulse wave; fiducial point; detection; uncertainty

1. INTRODUCTION

Detection and processing of arterial blood pulsation signal is widely used in instrumental cardiological diagnosis for monitoring heart rate, saturation of hemoglobin with oxygen, and arterial blood dynamics in blood vessels. However, the problems of minimization of errors caused by inaccurate detection of the fiducial points (mainly beat points, related to heart contraction) of pulse wave signal remain insufficiently studied. The procedure for detecting the fiducial points should provide reliable detection in the presence of high amplitude interference of variable origin. The following most discernible points of the pulse wave signal are usually selected as fiducial: systolic maximum, arterial pulsation minimum, and maximum of the first derivative signal.

2. MATERIALS AND METHODS

The model pulse wave signal was obtained by using a dynamical model developed by P.E. McSharry and coauthors . Motion artifacts were simulated using additive harmonic signal with frequency 4 Hz and noise with zero mean weighed by Hamming window:

$$N(t) = N_{\max}(\sin(2\pi f_1 t) + \xi(t)) \cdot [0.54 - 0.46 \cdot \cos(2\pi f_2 t)] \qquad (1)$$

where Nmax is artifact's amplitude; f1 is frequency of harmonic signal (4 Hz); ξ(t) is normally distributed random noise filtered by a low-pass filter with cut-off frequency of 5 Hz; the value of f2 is inversed to the duration of Hamming window (10 sec).

Analysis of the factors affecting appearance of baseline drift in the pulse wave signal showed that this type of noise represents a low-frequency signal arising stochastically and can be described as an additive combination of deterministic and random components :

where Nmax is the amplitude of the noise signal, determining the intensity of the baseline drift; fi is the set of frequencies for an additive set of harmonic signals representing the deterministic components of the noise signal; fs is the sampling frequency; and ψ(k) is the random component, obtained by filtering the white Gaussian noise using a low- pass filter with cut-off frequency of 0.8 Hz. In this case we used the frequency values f1, ..., f4 are equal respectively to 0.1, 0.2, 0.4, 0.8 Hz.

Electrical interference is generated as a result of external electromagnetic fields and can be described by using harmonic functions.

The time position of the fiducial points of pulse wave signal is detected with an error caused by noise and interference. The test of the efficiency of fiducial points detection is based on the deviation of duration of beat-to-beat intervals. The uncertainty of beat-to-beat intervals was estimated using quantile characteristics (confidence P within interval ±ΔP). The detection error was determined at P = 0.9, because in this case it is consistent with the mean square deviation for any distribution law . At P=0.9, the absolute error is:

$$\Delta_{\mu} = 1.6 \cdot \sigma_{\mu} \qquad (2)$$

where Δu is the uncertainty of beat-to-beat intervals; σu is the mean square deviation of beat-to-beat intervals from true value:

$$\sigma_{\mu} = \sqrt{\frac{\sum_{I=1}^{N} (PP'(i) - PP(i))^2}{N}} \qquad (3)$$

where PP(i) is true value of beat-to-beat intervals; PP′(i) is measured value of beat-to-beat intervals; N is the total number of beat-to-beat intervals.

The detectors of the fiducial points of pulse wave often contain a band-pass filter for raw eliminating noise and interference. This filter minimizes low frequency interference caused by respiration and slightly reduces the intensity of broadband noises, such as motion artifacts as well as distortions caused by electrical power line.

The efficiency of the band-pass filter could be determined by the signal-to-noise ratio at the filter output. A Butterworth filter can be used as a digital filter for preliminary filtering of pulse wave signal. The Butterworth filter has such advantages as flat frequency characteristic within the pass-band and low requirements for computation power. Therefore, a high order Butterworth filter with sharp spectral characteristic can be easily developed.

Upper and lower frequency limits of the band-pass filter are determined using an additive signal containing the model pulse wave signal and the interference signals. Let us consider the changes in the signal and interference amplitudes in the case of band-pass filtering. The filtration coefficient providing quantitative evaluating the degree of filtering is determined as follows:

kf=A’/A (4)

where A′ is the amplitude of the signal or interference at the band-pass filter output; A is the amplitude of the signal or interference at the band-pass filter input.

Dependences between the signal and interference filtration coefficients and the upper and lower frequency limits of band- pass filters of different orders are shown in Figs. 1 and 2, where traces 1, 2 and 3 correspond to filtration coefficient of a pulse wave for the filter’s order 4, 8 and 12, respectively; traces 4, 5 and 6 correspond to filtration coefficient of an interference for the filter’s order 4, 8 and 12, respectively

It follows from the curves shown in Figs. 1 and 2 that an increase in the lower frequency limit of the band-pass filter reduces the amplitude of the signal and the respiration induced interference in the biological signal. Excessive increase in the lower frequency limit distorts the shape of the arterial blood pulsation signal. On the other hand, an increase in the upper frequency limit reduces the amplitude of electromagnetic interference caused by the electric power line.

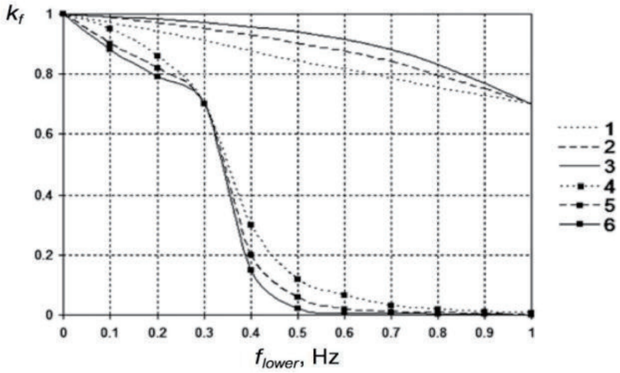

Figure 1. Dependences between filtration coefficients of signal and interference and lower cutoff frequency of band-pass filter

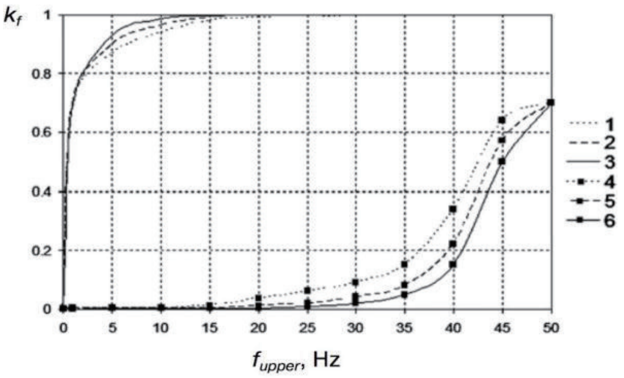

Figure 2. Dependences between filtration coefficients of signal and interference and upper cutoff frequency of band-pass filter

Thus, the lower and upper frequency limits of the band pass filter can be reasonably selected to be 0.5 and 15 Hz. Such band-pass filtering suppresses interference (40 dB for electric power line interference and 30 dB for respiratory interference), while the decrease in pulse wave signal does not exceed 1 dB.

Threshold function parameters were chosen empirically as a result of research by maximizing the correct detection of pulse wave beats and minimizing false alarms and omissions.

The detector of maximums determines the position of the maximums of the first derivative of pulse wave signal. The maximum is detected if the following conditions are met:

$$P_3(n)>P_3(n+1)\ \&P_3(n)>P_3(n-1) \quad (5)$$

3. RESULTS

The efficiency of various detectors of pulse wave beats was compared using a model signal at the presence of different noises and interferences. The efficiency of detection was estimated by using the signal-to-noise ratio Ka in dB:

$$K = 10\lg\frac{p_s}{p_n} \quad (6)$$

where Pn is the total spectral power of the noise signal, which in general is an additive combination of baseline drift, motion artifacts and electrical interference; Ps is the total spectral power of the model pulse wave signal.

The dependences between the uncertainties of beat-to-beat intervals and signal-to-noise ratio Ka are shown in Fig. 3 for different detectors in the presence of baseline drift and electrical interference only, where trace 1 reflects BP detector; trace 2 – MAF detector; trace 3 – FD detector; trace 4 – proposed detector.

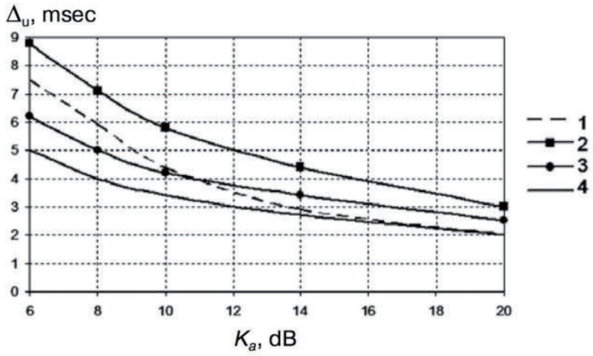

Figure 3. Dependences between the uncertainties of beat-to-beat intervals and signal-to-noise ratio Ka in case of baseline drift and electrical interference

The uncertainties of beat-to-beat intervals in the case of preliminary processing by using band-pass filter (12th order Butterworth filter with band-pass 0.5 – 15 Hz) should be tested independently. Dependences between uncertainties of beat-to-beat intervals and the amplitude ratio Ka in the case of band-pass filtering as preliminary processing stage are shown in Fig. 4 for different detectors of pulse wave beats. The efficiency of the pulse wave beat detectors should be additionally compared in the case of simultaneous presence of motion artifacts, respiratory and electrical interferences. Dependences between uncertainties of beat-to-beat intervals and the signal-to-noise ratio Ka for different detectors in case of simultaneous presence of baseline drift, motion artifacts and electrical interference are shown in Fig. 5. The band-pass filter is still used as preliminary processing stage of pulse wave signal.

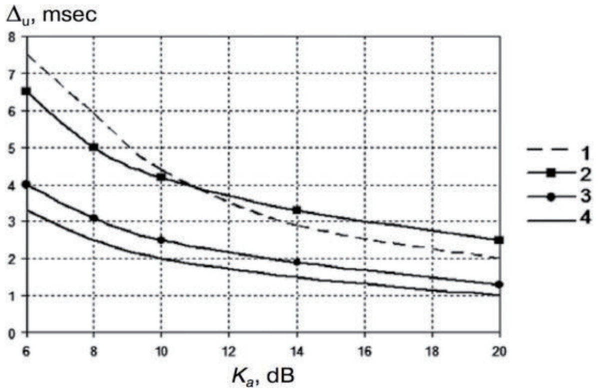

Figure 4. Dependences between uncertainties of beat-to-beat intervals and signal-to-noise ratio Ka in case of baseline drift and electrical interference and preliminary processing of pulse wave with the band-pass filter

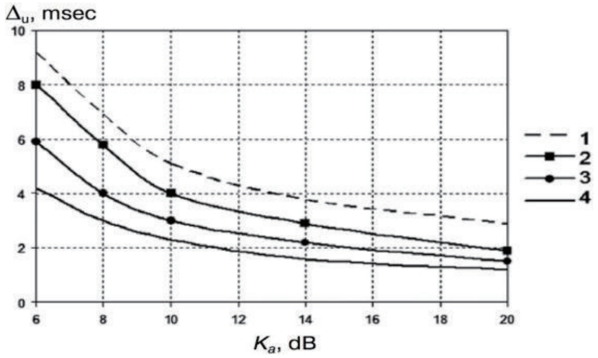

Figure 5. Dependences between the uncertainties of beat-to-beat intervals and signal-to-noise ratio Ka in case of simultaneous presence of baseline drift, motion artifacts and electrical interference

CONCLUSION

It can be seen from Fig. 3 that a decrease in the signal-to- noise ratio increases the error of detecting pulse wave beats. It can also be seen that the proposed detector provides minimal error.

Analysis of the results shown in Fig. 4 suggests that band- pass filtering during preprocessing decreases the error in measuring beat-to-beat intervals for all detectors. The minimal error is inherent in the proposed detector.

As follows from Fig. 5 motion artifacts lead to a considerable increasing the error in measuring beat-to-beat intervals for all detectors. Under the influence of motion artifacts, the approaches based on the first derivative operator and the proposed amplitude-time detection method perform better than the other detectors.

REFERENCES

[1] J.Allen, “Photoplethysmography and its application in clinical physiological measurement,” Physiological Measurement, vol. 28, pp. 1–39, 2007

[2] J.G. Webster, Design of Pulse Oximeters. The Medical Science Series, Taylor & Francis, 1997, 260 p.

[3] N.W. Townsend, R.B. Germuska, “Patent US 2005/000479 A1, USA, A61B 5/02. Location features in a photopletysmograph signal”, 2005, 19 p.M. Aboy, “An automatic beat detection algorithm for pressure signals,” IEEE Transactions on Biomedical Engineering, vol. 52, issue 10, pp. 1662–1670, 2005.

[4] M. Aboy, C. Crespo, J. McNames, B. Goldstein, “Automatic detection algorithm for physiologic pressure signal components,” Proceedings of 24th International Conference IEEE Engineering in Medicine and Biology Society and Biomedical Engineering Society, vol. 1, pp. 196– 197, 2002.