High-pass Filtering of Cardiogenic Electrical Impedance Signals

Assist. Prof. Galidia Ivanova Petrova - Technical University - branch Plovdiv,
61 Sankt Peterburg Blvd., Plovdiv 4000
Prof. D. Sc. Ivan Konstantinov Daskalov - Centre of Biomedical Engineering,
Bulgarian Academy of Science

Abstract. The typical impedance signal recorded from the thorax has a basic component (Z_o) and a pulsatile component (ΔZ), caused by cardiovascular activity. In order to avoid as much as possible any eventual changes in the ΔZ signal shape, usually a first order high-pass filter is used to separate ΔZ from the basic impedance Z_o. The purpose of our work was to determine the appropriate time constant value, which does not attenuate significantly the cardiac component of the impedance signal. The reference ΔZ signals are recorded with large time constant $\cdot\tau$=5s from a group of two female and three male volunteers. These ΔZ signals are further used as reference signals stored and reproduced from an ICG simulator. For every reference ΔZ signal a set of records with different time constant values (τ=5s, 4s, 3s, 2s, 1s) is taken. To compare different time constant responses two parameters of the ΔZ signal are evaluated - the amplitude of the leading slope (FDIF) and the amplitude of the falling slope (SDIF). They are derived on the basis of identification characteristic points in the records. The results show that the SDIF is most significantly influenced by the high-pass filter time constant value. Obviously a partial differentiation of the signal occurs. The FDIF is reduced more than 1.7% for the time constant τ=1s in comparison with the reference signal (τ=5s). With time constant value of 2s 1% accuracy is achievable for most cases of cardiac impedance recording, but for the extreme cases (low heart rate) time constant τ=3s is necessary to keep the error of ΔZ signal attenuation within 1%. Taking into consideration these results we would recommend a time constant value of 3s for use in impedance cardiographs.

Keywords: Electrical impedance, cardiac component, high-pass filter, time constant.

Introduction

Impedance cardiography, as a noninvasive cardiovascular monitoring technique, has been developed and used to calculate stroke volume, cardiac output and some other hemodynamic parameters. The typical impedance signal recorded from the thorax has a pulsatile cardiac component (ΔZ) with amplitude of 0.05-0.2Ω. In order to avoid as much as possible any eventual changes in the ΔZ signal shape, usually a first order high-pass filter is used to separate ΔZ from the basic impedance

Z_o. The desire to preserve the low-frequency components of ΔZ signal leads to the requirement for a large value time constant (τ) of the filter, but from another point of view this increases the baseline fluctuations and transient periods.

Our review showed that the time constant value in commercially available impedance cardiographs vary between 4s and 1s [1], [2], [3]. This provoked us to undertake a study for determination of an adequate time constant value, which does not alter significantly the cardiac component of the impedance signal.

Method and algorithm

The reference ΔZ signals are recorded from a group of two female and three male volunteers, acquired with large time constant τ=5s and breath holding in order to avoid respiratory changes. An example of two of these signals together with their power spectra is shown in Figure 1. It is evident that the frequency of the first component in the power spectrum and the higher ones correspond to the cardiogenic component of the signal. No breathing components are present in the power spectra (the comparatively small signals below 1Hz are considered as noise). The signals are recorded on IBM PC computer using a 12-bit A/D converter and sampling frequency of 1024Hz. After normalization and recording in EPROM, they are further used as reference signals stored and reproduced from an ICG simulator. The ICG simulator is in fact a digital signal synthesizer. A FET is used as a voltage variable resistor at the output, thus simulating the cardiogenic component of the impedance.

For every reference ΔZ signal a set of records with different values of the time constant (τ=5s, 4s, 3s, 2s, 1s) is taken. To compare different time constant responses two parameters of the ΔZ signal are evaluated. The first one is the amplitude of the leading slope (FDIF). It is defined as the difference between the point of upward deflection (anacrotic notch - B-point), corresponding to the beginning of the ejection period, and the maximum (M-point) - Figure 2. The B-M time interval corresponds to the peak of the differentiated ΔZ signal (dZ/dt_{max}), which is an important parameter in calculation of stroke volume. The second parameter is the amplitude of the falling slope (SDIF) of the ΔZ signal. It is defined as the difference between maximum (M-point) and the point of downward deflection (dicrotic notch - C-point), corresponding to the end of the ejection period. Calculation of FDIF and SDIF requires accurate identification of the B, M, C-points for every period of the records.

The following steps describe the algorithm used:

(a) The first scan proceeds within the whole data of the corresponding record to determine the value and location of the global minimum.

(b) A second search is performed to find the local minima for every period in the record.

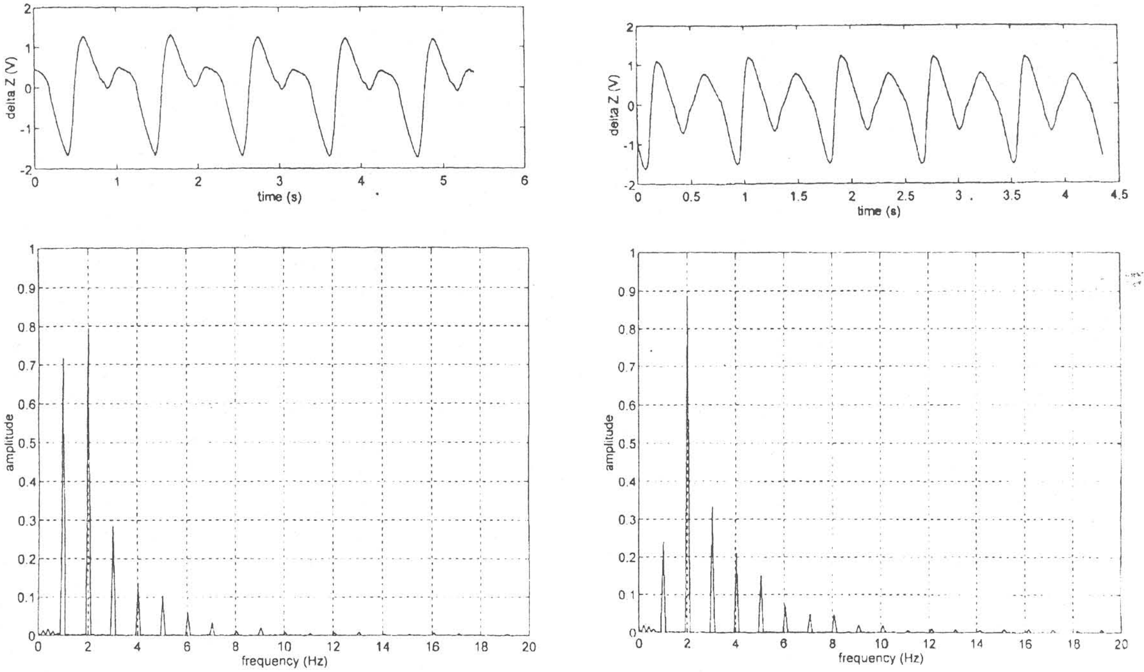

Figure 1. Two of the reference signals, obtained with time constant of 5s, together with their power spectra.

(c) The data are processed to find the maximum (M-point) value and location between adjacent minima.

(d) Starting from M-point to the left on a point-by-point basis along the ΔZ, at each point the both sides slopes are calculated and compared. The decision rule for B-point identification should meet two conditions. First the B-point is defined as the point where the slope towards the right exceeds the slope towards the left by the greatest value [4]. Second, to assure noise immunity, the value of B-point has to be within 10% with respect to the value of the local minimum.

(e) The next step is identification of C-point. Starting from M-point to the right, at each point the slopes on its either side are calculated. C-point is defined as the point where the slope changes its sign. The second condition rule is met if for the next three points the same slope sign is kept.

(f) The amplitudes of the leading and falling slopes of the ΔZ signal for every period of the record are calculated. By averaging the results over five complete cardiac cycles, the two parameters FDIF and SDIF for every record are obtained. FDIF and SDIF of the record with $\tau=5$s are taken as the reference. The percentage error is then calculated for the other records with different value of the time constant.

Results and discussion

Figure 3 shows the percentage FDIF attenuation plotted against the different time constants. The FDIF is reduced with more than 1.7% for a time constant $\tau=1$s in comparison with the reference signal ($\tau=5$s). With time constant value of 2s 1% accuracy is achievable for most cases of cardiac impedance recording. However, for extreme cases (especially low heart rate), as for example patient N^{o} 4 having heart rate of 56 bpm, a time constant $\tau=3$s is necessary to keep the error of ΔZ signal attenuation within 1%.

Figure 4 shows the percentage SDIF error for different time constants. SDIF is most significantly influenced by the high-pass filter time constant value. Obviously a partial differentiation of the signal occurs. This effect is stronger with lower time constant of the high-pass filter. With time constants of 3s, the percentage error is within 1.5%.

We consider that the time constant of 1s, frequently used in impedance cardiographs, can lead to distortions and errors in ΔZ signal. An example is shown in Figure 5. The reference signal acquired with $\tau=5$s and the signal acquired with $\tau=1$s are superimposed taking the maximum M-point as common for both signals. Slight shape distortions and observable amplitude reduction of the signal acquired with $\tau=1$s can be seen. The arrows point the characteristic B- and C-points.
Taking into consideration these results we would recommend a time constant value of 3s for use in impedance cardiographs.

References

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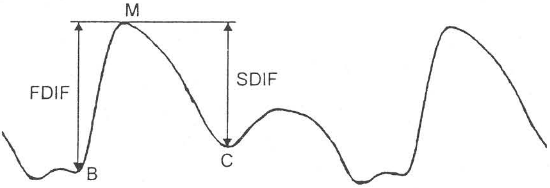

Figure 2. The amplitudes of the leading (FDIF) and the falling slope (SDIF are evaluated for every period of the recordings.

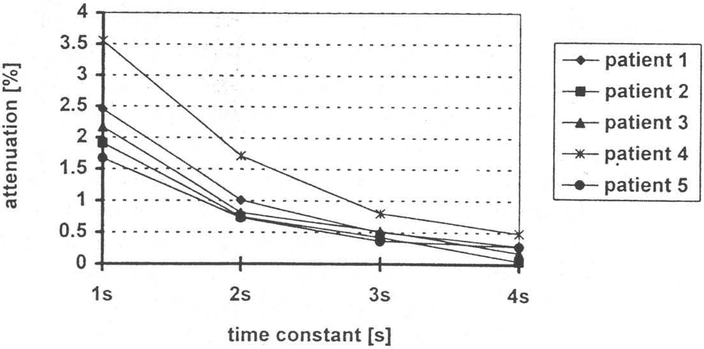

Figure 3. FDIF attenuation for different time constants.

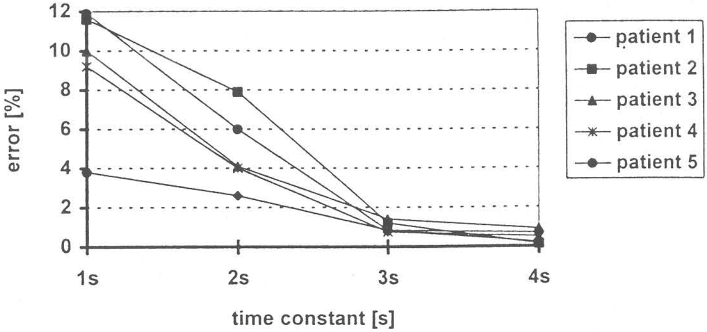

Figure 4. SDIF error for different time constants.

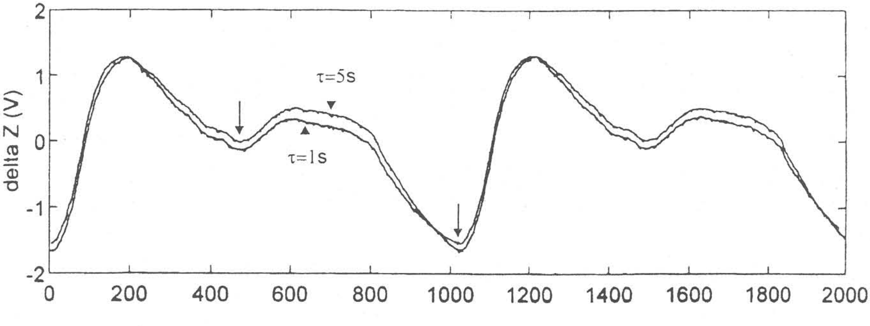

Figure 5. Superimposed reference signal and the signal, acquired with time constant of 1s. The observable amplitude errors can be seen.