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Certain aspects of bioelectrical signal smoothing.

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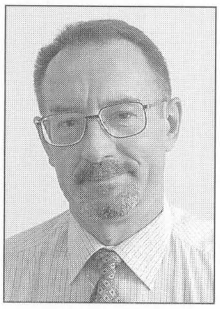

absolwent Wydziału Elektrycznego Politechniki Poznańskiej (1972, specjalność: automatyka). W latach 1972 - 1976 pracował na Akademii Medycznej w Poznaniu. Od 1976 zatrudniony w Politechnice Szczecińskiej, gdzie na Wydziale Elektrycznym uzyskał stopień doktora nauk technicznych (1984). Obecnie adiunkt w Instytucie Elektroniki, Telekomunikacji i Informatyki, kierownik Zakładu Cybernetyki i Elektroniki. Od początku pracy zawodowej zajmuje się inżynierią biomedyczną, w szczególności zagadnieniami obiektywizacji badań układu wzrokowego.Jest autorem i współautorem ponad stu publikacji poświęconych głównie tej tematyce.

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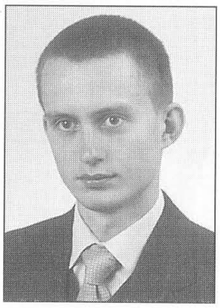

Absolwent Wydziału Elektrycznego Politechniki Szczecińskiej (2002, kierunek: elektronika i telekomunikacja). Obecnie uczestnik II roku studiów doktoranckich na tym wydziale. Jego zainteresowania naukowe dotyczą analizy i przetwarzania sygnałów bioelektrycznych, szczególnie z zastosowaniem metod czasowo-częstotliwościowych oraz sieci neuronowych. Jest autorem i współautorem dziewięciu publikacji, w tym czterech referatów prezentowanych na konferencjach międzynarodowych. Obecnie przygotowuje pracę doktorską poświęconą przetwarzaniu sygnałów bioelektrycznych powstających w układzie wzrokowym.

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absolwent Wydziału Elektrycznego Politechniki Szczecińskiej (1979, specjalność: automatyka i metrologia elektryczna). W 1983 r. uzyskał stopień doktora nauk technicznych. Stopień doktora habilitowanego nauk technicznych uzyskał w 1991 r. na Wydziale Elektrotechniki i Technik Informacyjnych, Uniwersytetu w Ilmenau. Obecnie profesor nadzwyczajny Politechniki Szczecińskiej. Od początku pracy zawodowej zajmował się badaniami dotyczącymi komputerowej analizy zagadnień wiroprądowych, ekranowania elektromagnetycznego, procesów dyfuzyjnych i modelowania dynamiki tych procesów, a obecnie przetwarzaniem sygnałów biomedycznych. Jest autorem i współautorem blisko 40 artykułów w czasopismach naukowych.

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Abstract

Signal averaging plays an important role during the process of biomedical signal acquisition and further analysis. It allows smoothing of the waveform and noise suppression. It has, however, a significant disadvantage, which is elongation of the recording process, because many iterations of the same signal have to be acquired. In certain circumstances it can seriously complicate the exami-nation, or even prevent its completion. This study concerns a concrete example of such signals: transient PERG waveforms, which are electrical responses of the human retina to a special light stimulus. Among many other methods of clinical electrophysiology of vision, PERGs are consid-ered especially useful in the diagnosis of glaucoma. Due to their low amplitude and high noise content many single responses are usually averaged in order to obtain "readable" result. This paper analyzes the influence of the number of averages on PERG "readability" and discuses the applica-tion of alternate signal processing methods.

Streszczenie

W przypadku rejestracji i analizy sygnałów biomedycznych charakteryzujących się bardzo niską amplitudą oraz obecnością zakłóceń standardową praktyką jest wielokrotne uśrednianie zarejestro-wanych realizacji sygnału. Pozwala to na wygładzenie przebiegu i eliminację przypadkowych zakłóceń. Ma jednak swoją cenę, którą jest wydłużenie czasu rejestracji sygnału. W pewnych warun-kach utrudnia to (lub wręcz uniemożliwia) ukończenie badania. Takimi sygnałami są np. elektrore-tinogramy, czyli zapisy czynności elektrycznej siatkówki wykorzystywane w diagnostyce okulistycznej, a w szczególności sygnał transient PERG (tzw. elektroretinogram patternowy - wywołany wzorcem). Praca przedstawia analizę wpływu liczby uśrednień na „czytelność" sygnału PERG oraz rozważa wykorzystanie alternatywnych metod poprawy jego jakości.

1. Introduction

Recordings of the electrical activity of human eye may provide many useful information about patient's health state. The electroretinography is a medical examination conducted in order to diagnose the state of the retina. Retina is a light-sensitive part of our eye, the structure responsible for creating and pre-processing the electrical response for the visual stimulus. This response is passed to the brain by the optical nerve and processed in the visual cortex.

For diagnostic purposes an electrode (which conducts electric impulses generated by the retina) is placed on the cornea (see fig. 1), and a special kind of visual stimulus is presented to a patient (see fig. 2). Depending on parameters of the stimulus, different kinds of electroretinograms are obtained. When the retina is stimulated by alternating black and white chessboard (with constant total luminance) a PERG is recorded. The frequency of the board flickering decides if a "transient" or rather "steady-state" shape is going to be evoked. In this paper we discuss only the case of "transient" PERGs, which are generated when the frequency is lower than approximately 6 Hz. Its amplitude is about 10 μV. A single waveform lasts usually about 200 ms, but unfortunately contains many artifacts (which must be rejected) and significant amount of noise (originating from muscle contractions and 50 Hz frequency components). For this purpose usually over 150 recordings are summed and average values are computed.

The main kinds of electrophysiological examinations were standardized by the ISCEV (In-ternational Society for Clinical Electrophysiology of Vision). However, these "standards" are rather a set of general guidelines than numerical limits of a correct shape. They are also often updated. These updates are usually published in the "Documenta Ophtalmologica" journal [1] and on the ISCEV's website. Currently the clinical evaluation of PERG is based on measurement of the local maxima and minima. These are often called "waves". Three following waves can be distinguished from the waveform: N35, P50, N95. The letter stands for "positive" or "negative" component, whereas the number stands for the approximate time (expressed in milliseconds) when the particular components appear (fig. 3). It appears that detection of changes in the parameters of PERG compo-nents is useful as a diagnostic tool in several disorders affecting this level of optical stimulus proc-

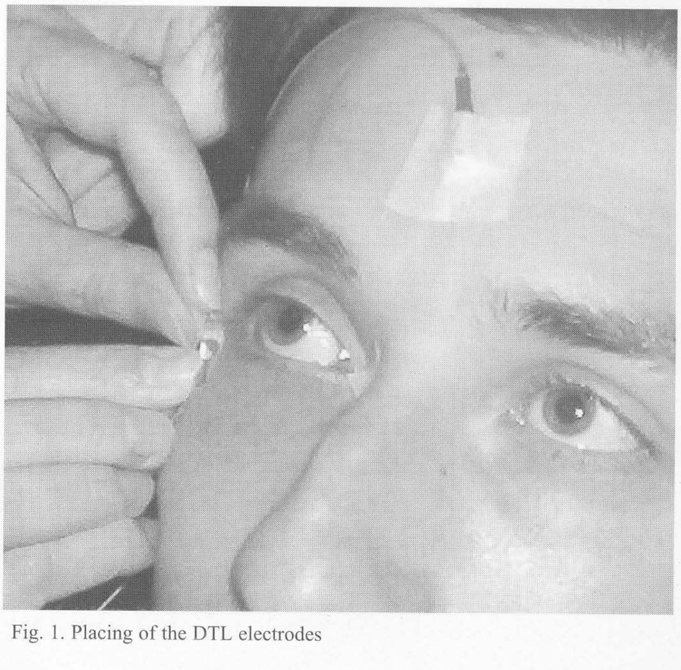

Fig. 1. Placing of the DTL electrodes

essing and causing retinal dysfunction. PERG is especially important in early detection of glaucoma [3,6]. The authors, in co-operation with Pomeranian Medical Academy in Szczecin, do research devoted to processing and classification of these signals. Initial results of their work were presented in [7,8].

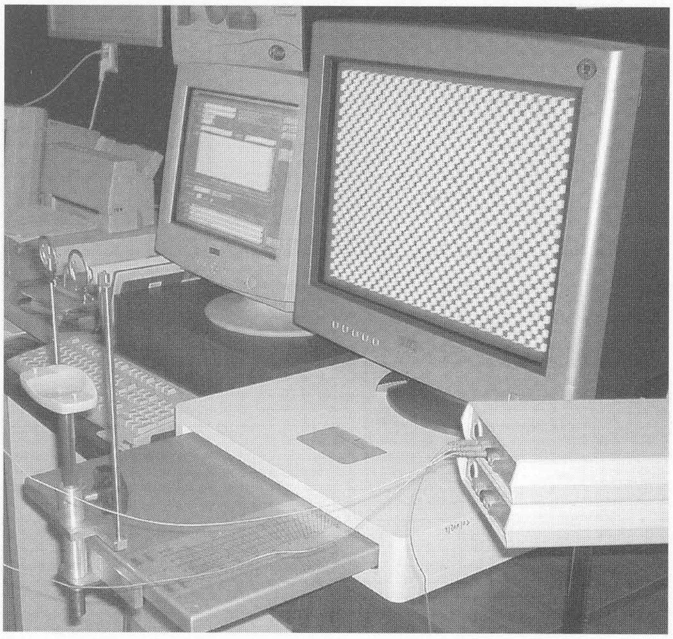

Fig. 2. The RetiPort system during PERG acquisition

2. Data acquisition process

The data used in the research were recorded in 2nd Clinic of Ophthalmology of Pomeranian Medical Academy in Szczecin, using RetiPort system, produced by the Roland-Consult company [9]. A single PERG waveform lasts about 300 milliseconds and its peak-to-peak amplitude ranges from about 5 to 15 microvolt. Electrical model of the observed phenomenon is described in [3]. Each recorded waveform is stored using 512 samples. The photographs of the electrodes and the RetiPort system are presented in fig.1-2. Fig. 3 shows four sample waveforms coming from both healthy and unhealthy patients.

The diagnostic system allows exporting the results in CSV (comma separated values) for-mat. These files need further processing before importing into computing environment. Performing this operation required auxiliary programs to be written (in Python programming language). After the conversion the data were imported to the Matlab software. Acquisition of unaveraged signals is not a standard medical practice. Thus the analyzed data must have been obtained solely for this study. Diagram of the recording system is presented in fig. 4.

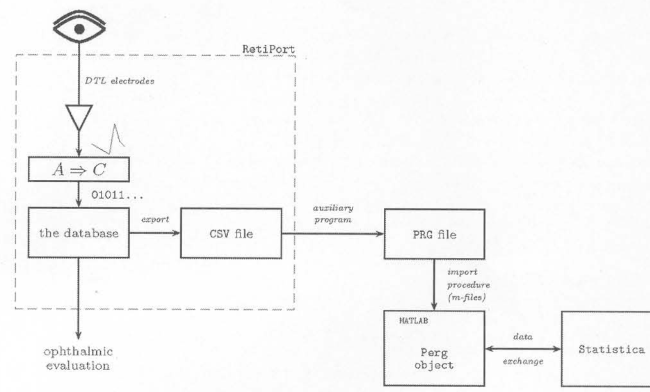

Fig. 4. Diagram of the recording system

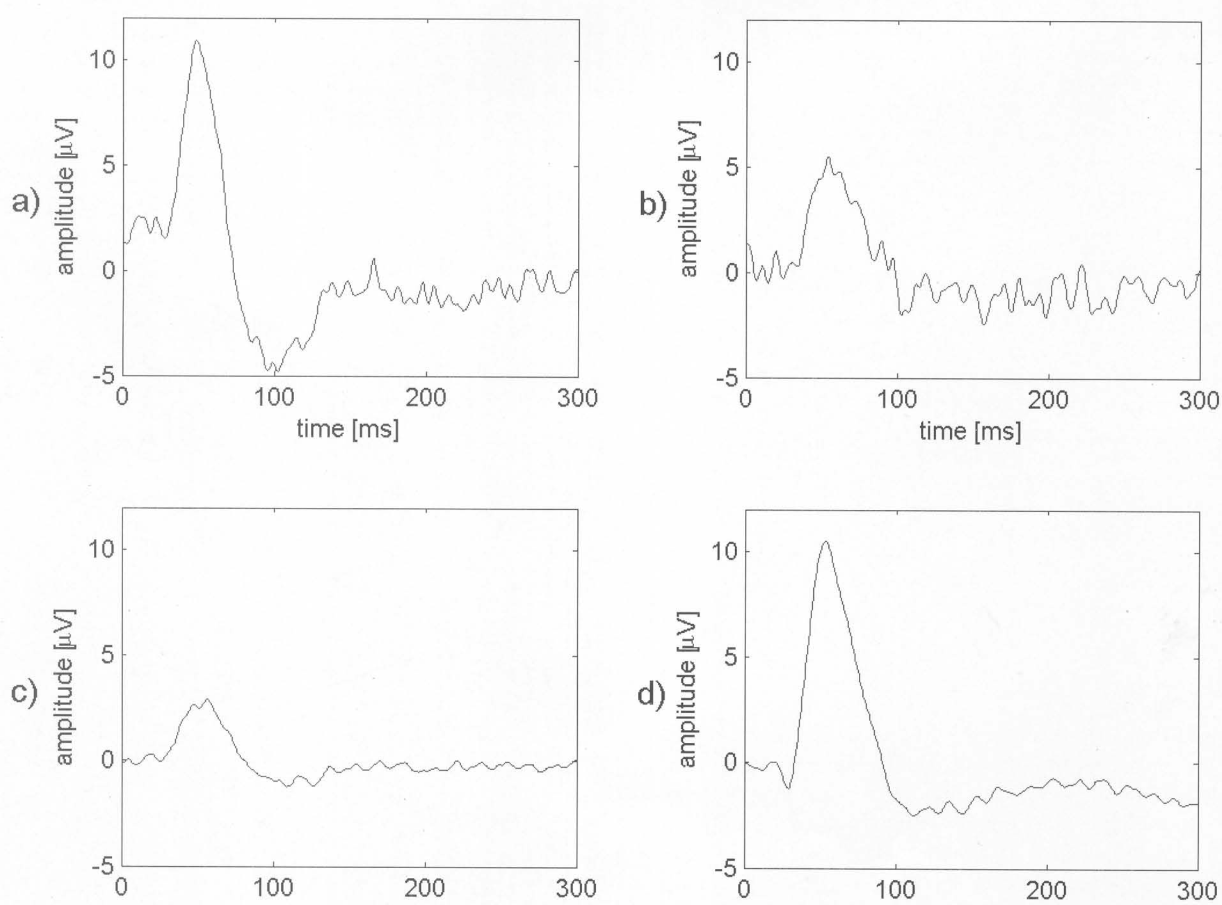

Fig. 3. Sample PERG recordings. a) correct shape, b) correct shape with significant content of noise, c) amplitudes below required level, d) incorrect N95 to P50 amplitudes ratio

3. The role of signal averaging

Usually, in order to obtain final examination result, many waveforms are summed and aver-aged (at least 150 according to PERG standard [1] by ISCEV). During the recoding waveforms containing artifacts are rejected. Detection of the artifacts uses simple thresholding, since these components have generally the shape of narrow spikes. Whenever the amplitude of the currently recorded waveform exceeds certain value (called artifact rejection threshold) it is rejected. The ex-amination is complete after the required number of correct repetitions is obtained. Cooperation with the patient is very important during the acquisition. A relaxed body position prevents artifacts coming from muscle contractions. The sight must be fixed exactly on the screen displaying the stimulus. The longer lasts the examination, the more difficult is to fulfill these requirements. It is the problem concerning not only PERGs, but also other signals used in clinical electrophysiology of vision.

Along with the increasing importance of electrophysiology in vision diagnosis, there are many attempts made in order to enable examining of "uncooperative" patients (e.g. children). Al-though the main goal of studies dealing with signal averaging is to provide better SNR (see Davila's paper [2] as an example and for further reference), there exist some papers dedicated to the reduc-tion of required number of averages, shortening the recording procedure. Such an idea is presented in Meigen's article [5] discussing the case of transient PERGs.

The influence of the number of signal averages on PERG parameters is presented in fig. 5 . The figure contains several waveforms coming from the same healthy patient. All the recording parameters were equal, except from the number of summed and averaged responses. The results are summarized in the tab. 1. It is worth noticing, that there are some significant differences between determined parameters, especially concerning amplitudes ratio and N95 latency. The figure in-cludes two waveforms averaged five times. This is done on purpose, to show that the variability of described signal. Even if the number of averages is the same, the outcome may still differ signifi-cantly.

Analysis of waveforms from fig. 5 leads to conclusion, that the RetiPort software indicates a peak at the local amplitude minimum (pointed by arrow). Therefore these values are often corrected by the ophthalmologist.

The ISCEV guidelines say that "the peak should be designated where it would appear on smooth or idealized waveform" [1]. Hence it can be concluded that parameters obtained from the signal averaged 200 times, are not necessarily "the best" or "the most accurate". Thus the following assumption can be made: when the examination of "uncooperative" patient is needed, guidelines concerning the required number of averages do not have not be followed precisely, because the de-termined values would be corrected manually anyway. Instead, certain alternative processing methods could be applied.

parameter / averages	1	5	5	10	20	50	100	200
N35 [ms]	20	26	26	26	25	28	28	28
P50 [ms]	49	50	47	54	50	51	50	50
N95 [ms]	103	108	102	107	105	100	95	108
ampl. N35-P50 [μV]	24,9	15,4	14,3	11,3	13,3	12,2	13,7	13,4
ampl. P50-N95 [μV]	26,2	23,5	17,4	17,8	20,8	20,5	18,2	17
amplitudes ratio	0,95	0,66	0,82	0,63	0,64	0,60	0,75	0,79

Tab. 1. Parameters (exported from RetiPort system) of waveforms in the fig. 5.

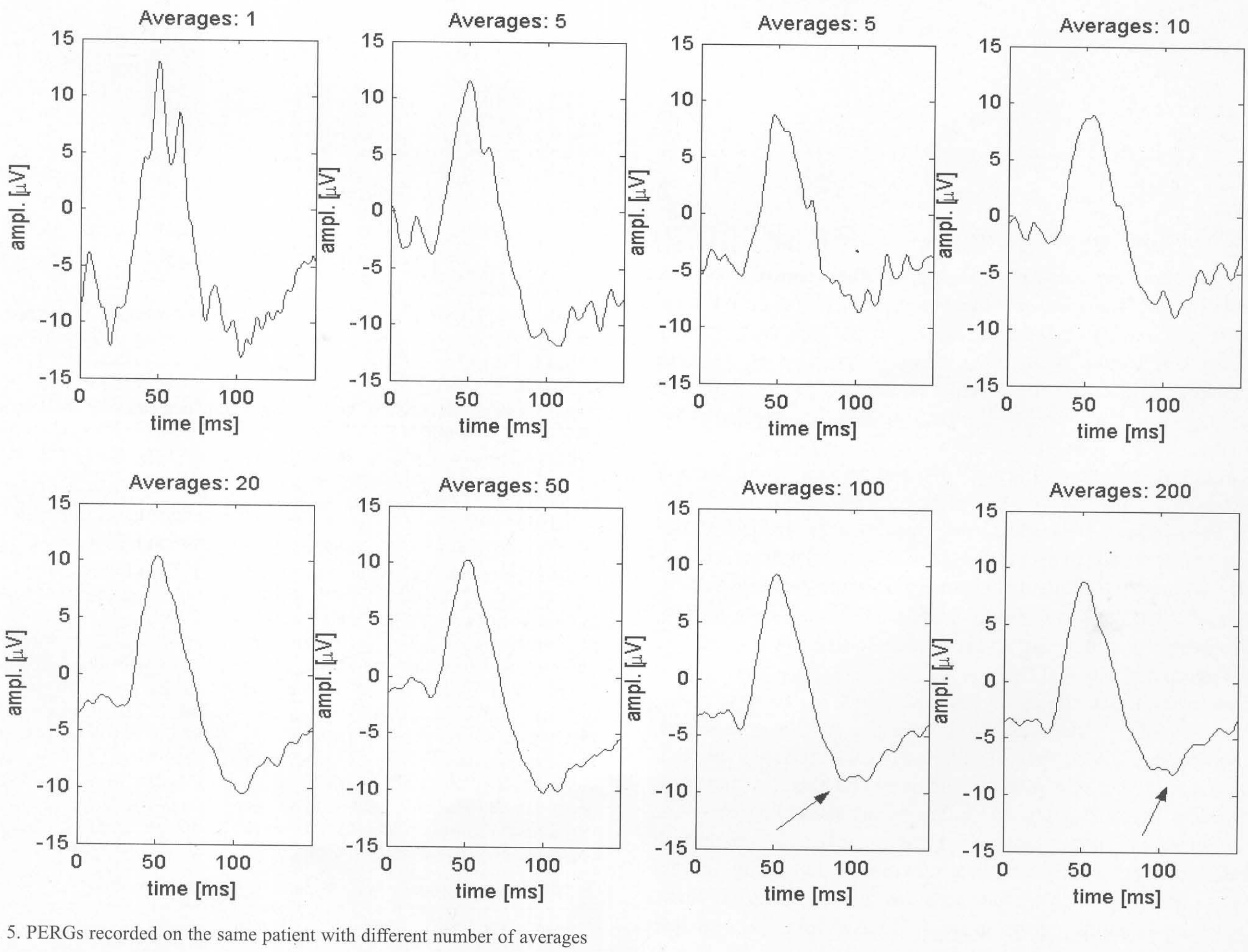

Fig. 5. PERGs recorded on the same patient with different number of averages

4. Proposal of alternative processing methods

In order to indicate the peaks, the waveform must be smoothed. This goal can be achieved in many different ways. Three investigated approaches are: median filtering, simple lowpass filtering, wavelet-domain filtering. Some initial results, presenting the bare concept rather than comparing the methods in detail, are shown in fig. 6. As an input signal the first waveform form fig. 5 was chosen. It is a "pure" unaveraged PERG response, but usually such a "roughness" is typical for sig-nals recorded with 5, 10 or even 20 averages.

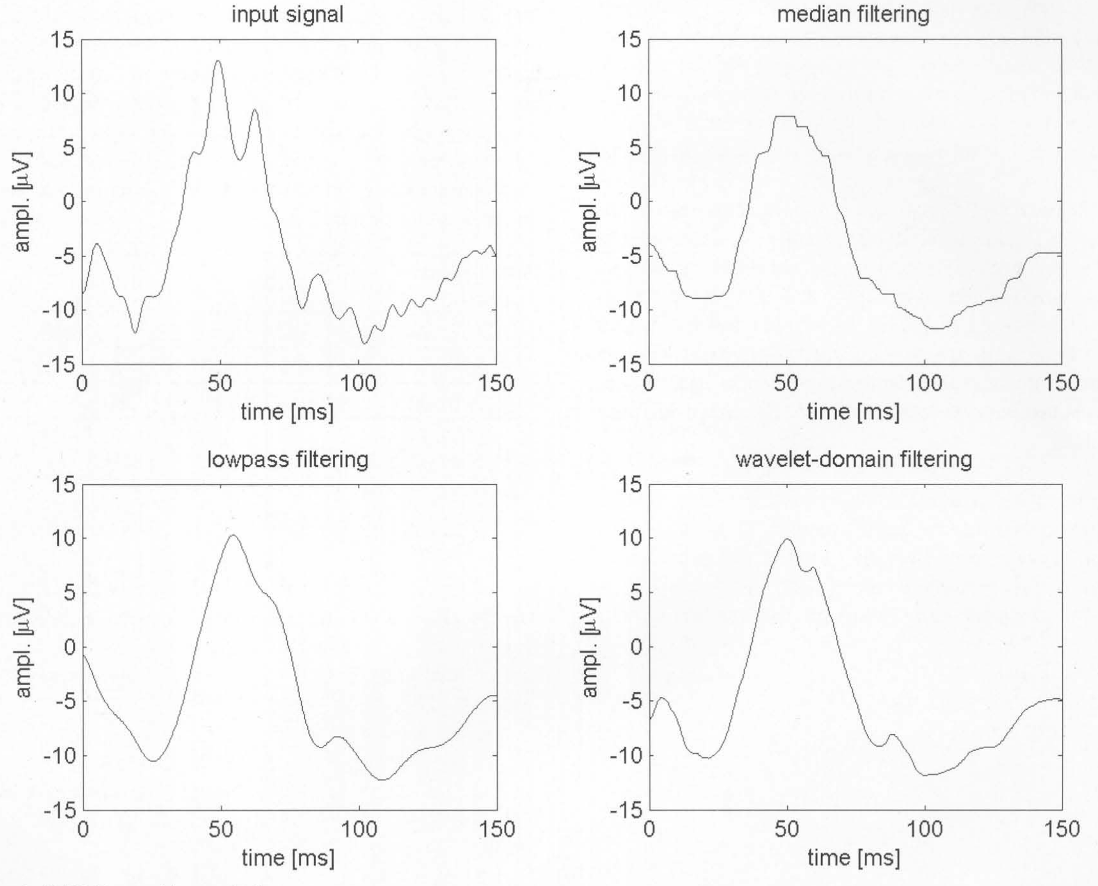

Fig. 6. Proposal of PERG smoothing methods

All the metioned ideas have their advantages and drawbacks. Median filtering [4] is the sim-plest to implement, because it does not need initial analysis of the signal. On the one hand it elimi-nates the redundant details, on the other the result could be too rough to be accepted by a doctor. It requires the choice of only one parameter: the filter order, which must be determined experimen-tally (it equals 25 in discussed case).

Digital lowpass filtering is a simple, fast and easy to implement operation [4]. However, to choose the cutoff frequency correctly, prior knowledge of the frequency spectrum is needed. Addi-tionally, it causes a temporal delay, which must be corrected to avoid "shifting" the whole wave-form. In this particular case a fifth order FIR filter, designed using the Parks-McClellan algorithm [4] (implemented in Matlab Signal Processing Toolbox) was used. The cutoff frequency was 100 Hz.

Wavelet analysis has become a standard signal processing routine nowadays. In comparison with the former approaches, wavelet-domain filtering is still a relatively sophisticated method. It is based on so-called "soft thresholding" of wavelet transform coefficients [4]. Although the choice of the filtering parameters does not require prior analysis of the signal, it is certainly a complex proce-dure. The results may vary, depending on the wavelet chosen for analysis (not each one guarantees proper noise suppression). Despite of the mentioned drawbacks the outcome seems satisfactory.

5. Conclusions

Signal averaging is certainly a very efficient way of smoothing the electrophysiological data. Un-fortunately it cannot be performed properly when the patient does not "co-operate". Then proposed alternative methods of smoothing the signal can be helpful. The choice of parameters depends on the prior knowledge about the examined phenomenon. The aim of this study was to introduce the bare concept of such a procedure, which can be useful when dealing with various biomedical sig-nals. Every practical application requires further detailed study and practical verification.

6. References

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Tytuł: Pewne aspekty wygładzania sygnałów bioelektrycznych

Artykuł recenzowany