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INFORMACIONE TEHNOLOGIJE

SADAŠNJOST I BUDUĆNOST

Urednik
Božo Krstajić

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METODE SOFTVERSKOG PROCESIRANJA BIO-POTENCIJALA
METHODS OF BIOPOTENTIALS SOFTWARE PROCESSING

Roman Golubovski, *Republic of Macedonia*

Sadržaj: *Moderne Informacione tehnologije omogućuju neograničene aplikacije signal procesiranja u Biomedicinskom inženjeringu bez nekada neibežnog analognog hardvera za instrumentacisko predprocesiranje. Ovaj članak ilustrira dve aplikacije softverskog procesiranja EEG i EKG biosignala.*

Abstract: *Modern ITechnologies allows for limitless applications of DSP (digital signal processing) in the Biomedical Engineering, avoiding the once unavoidable analogue hardware conditioning and instrumentation pre-processing. This paper depicts two prominent applications of software processing in the fields of EEG and ECG.*

1. INTRODUCTION

The EEG project application models the learning process in humans based on the classic conditioning theory. The DSP challenge was to extract the ERP (event-related potential) from the overwhelming EEG (electroencephalogram) "noise" and derive its anticipatory component - the CNV (contingent negative variation) wave. No classic filtering is applicable due to the fact that ERP is submerged in at least 1:10 ratio inside the EEG. So iterative averaging filter is defined that successfully extracts the ERP potential.

The ECG (electrocardiogram) project tackles with real, signal degraded and fast (typical neonatal) rhythms automating the standard ECG diagnosis. Commercial ECG devices do not analyze such fast rhythms, thus presenting a DSP challenge that can be met with a novel Mathematical Morphology (MM) method resulting into an 1D signal processing application.

2. THE EEG DSP APPLICATION

Brain potentials are divided into spontaneous and event-related. The spontaneous result from the regular brain activity also known as the EEG potentials. The event-related potentials (ERP) result from external brain excitation (event) and can be divided into *evoked* and *anticipatory*. Evoked potentials appear after the excitation as a reflex of the brain. Anticipatory potentials appear before the corresponding event and represent an expectation of the same and usually a motor preparation process for it in the brain. The most prominent example of the expectation-related potential is the contingent negative variation (CNV) potential.

The CNV experiment is based on the CNV paradigm which applies two brain stimuli (S_1 and S_2, usually audio) to the subject and with constant interstimulus interval (ISI). S_1 is a warning stimulus and S_2 is an imperative stimulus that the subject has to react on. The subject's reaction is applied to the experiment to prevent subject's concentration from lowering. The procedure is repeated tens of times, during which an ERP produced in the EEG trace between the stimuli shapes itself toward a specific CNV wave. The ERP after 10-20 trials can clearly show both components - the evoked (short) potential due to S_1 as well as the anticipatory (late, expectancy) potential together with the preparatory potential prior and due to S_2.

The DCNV (Dynamic CNV) experiment is an extension of the CNV experiment as defined above. The extension is actually a closed loop (bio-feedback) which enables switching S_2 ON and OFF the due to fulfilling certain conditions in the experiment's environment, thus forcing a cyclic process of building and degrading of the CNV wave. Subject is not informed about the nature of both stimuli, so the expectation of appearance (absence) of S_2 during the experiment completely corresponds to the learning process. This allows modeling of the learning process. The CNV wave (extracted ERP) can be qualified by one of its parameters like amplitude, slope, etc. After the experiment, a statistical curve of the qualifying parameter (one of the mentioned) is drawn across the trials. This statistical curve is denoted as the *electroexpectogram* (EXG) and directly presents the subject's cognitive capabilities. Typical EXG curve is presented on figure 3. As current researches at the Institute of physiology indicated, it is expected future clinical researches at the Clinic of neurology to demonstrate distinctive differences in this statistics between different categories like: healthy and patients with some kinds of neurological disturbances (epileptic, etc.), or children and adults, etc.

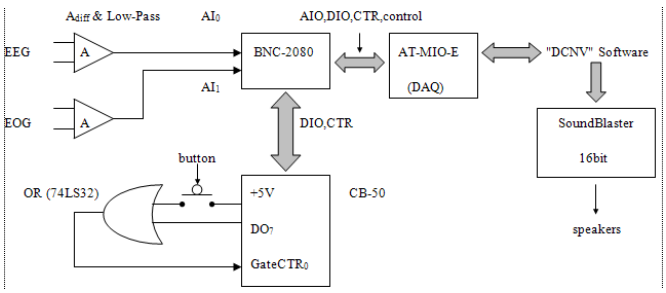

Figure 1. The hardware setup

The hardware setup shown on Figure 1 is organized around a general purpose acquisition board performing DAQ in the μV range.

The system acquires two differential analogue channels, the EEG and the EOG. The excitation is of type audio, S_1 being a short (0.5s) 1kHz warning beep and S_2 being a longer (3.2s) 2kHz imperative beep. It is essential that the subject is not aware neither of the nature nor of the number of the stimuli. The acquisition lasts for 7s and is buffered and hardware timed. S_1 is issued in t=1s into the acquisition, S_2 is issued in t=3s if applied by the algorithm. During the experiment, the subject learns about the number, nature and order of the stimuli, thus demonstrating the process of learning by shaping the ERP wave toward the expected CNV. The subject has to react upon hearing S_2 by pressing the button and immediately stopping it. This is prevention from falling asleep and lowering of concentration. The number of trials in the experiment is set to maximum 100 successful (120 trials total). The *gap* between two consequent trials varies from 12-15s to avoid timing determinism. As mentioned in the introduction, the criterion for ERP being a CNV can be defined in several ways. It could be an ERP with amplitude at S_2 above predefined threshold, or an ERP with slope of its linearized interval between S_1 and S_2 above predefined threshold, or a combination of both. After three consequent CNVs detected, S_2 is turned OFF and the subject *learns to forget* the imperative stimulus thus lowering the value of the CNV-qualifying parameter. After three consequent NOT-CNVs, S_2 is turned ON again, and so on.

The EOG trace is used for automatic validation of the EEG trace against artifacts defined as voltage sequences longer and higher than preset thresholds. There is a second manual criterion applied, where the operator can reject current EEG if artifacts are recognized visually. Rejection of such trials is necessary since the process of extraction of the ERP uses a cumulative iterative filter that averages the acquired signal by ensemble, so every artifact that passes it will influent the extracted ERP till the end of the experiment.

Figure 2. Main panel

The main panel shows the acquired EEG signal in the current trial, the extracted CNV potential and its linearized model, as well as the required measurements and calculated values. The green (third) vertical marker on the CNV Morphology represents the reaction time of the subject. The yellow LED in the upper left corner of the REJECT button is ON for 3s after the end of the current acquisition allowing the operator for that period of time to reject it if significant artifacts are noticed on the EEG strip. Maximum of 120 trials can be performed (limit of subject's patience) but 100 successful are required. Measured values are the absolute offset (ref_0) and the reaction time (R_t). Calculated values are the amplitudes of the CNV wave at S_1 and S_2 - $A(S_1)$ and $A(S_2)$, having calculated the latencies of both stimuli, as well as the difference of the maximum and the minimum in the ISI - APP, the energy of the CNV wave in the ISI and the slope of the same calculated from the linearized model. "Gain" relates to the amplification, and **c** and **d** are parameters of the optimal cumulative filter for CNV extraction. The optimal filter in its iterative and explicit forms is as follows:

$$CNV_i = d \cdot CNV_{i-1} + c \cdot EEG_i$$

$$CNV_n = \sum_{i=0}^{n} d^i \cdot EEG_i$$

The stability of the filter is obviously achieved by keeping d<1, and d<c secures dominant influence of the current EEG sequence in the current CNV extraction.

Figure 4 shows the iterative CNV filtration with the corresponding EEG strips on Figure 3.

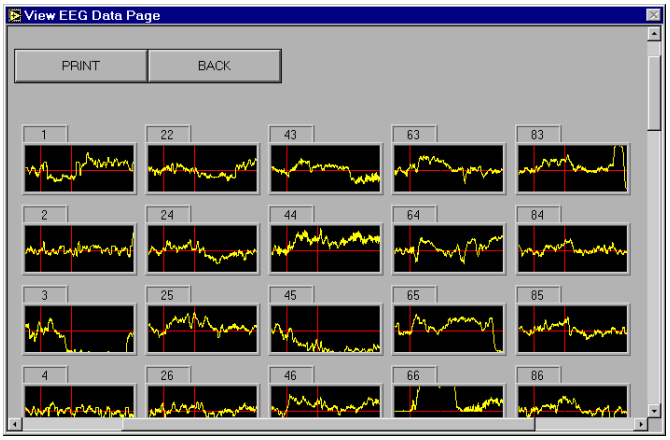

Figure 3. EEG history

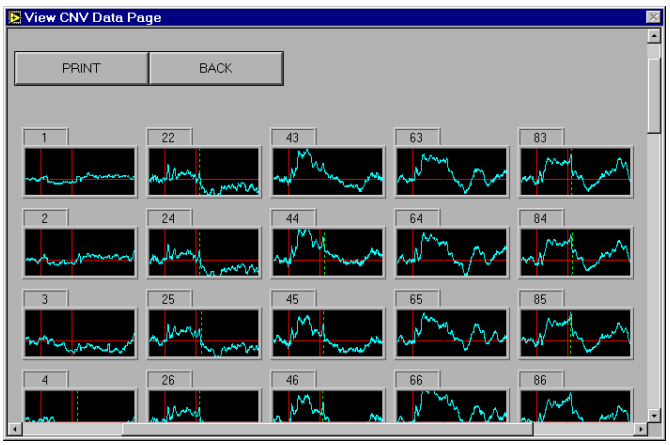

Figure 4. CNV history

The application is completely hardware-synchronized software. The acquisition is timed by the on-board clock of the acquisition card. The audio stimulation performed through the sound card is based on WAV strings prepared in the memory prior to the start of the experiment and triggered by the clock too. The reaction time is measured by the on-board counter, started by a digital output from the card issuing pulse at the same moment with the start of S_2 and stopped by the user press or the time-out pulse applied again by the same digital line.

3. THE ECG DSP APPLICATION

Acquired ECG signal is degraded by low-pass EMG drift modifying its baseline; and by power net interference, high-pass noise and A/D conversion compromising its morphology. One of the main problems in the automated ECG analysis is to filter out the baseline wander, and extract the isoelectric reference, thus enabling accurate measurements and morphology recognition. Using Gray-scale Mathematical Morphology (MM) primitive operators, accurate baseline extraction is performed in three steps. First is to determine the exact heart rate (HR), which is done by high-pass MM filtering and R-wave detection. In the second step, preliminary baseline estimation is performed using low-pass MM filtering, thus allowing accurate morphology recognition. In the third step, the baseline is corrected using the ending points of TP intervals (P-start) which are considered as truly isoelectric. This procedure allows accurate baseline extraction and recognition of the complete morphology, as well as measurements and calculation of all amplitudes, ST segment elevation and relevant intervals (P, QRS, RR, PR, QT, QTc). Mentioned parameters are filtered against artifacts by calculating their median values for whole strips. The Mathematical Morphology offers a reliable solution for the baseline extraction problem, allowing ECG analysis for holter and monitoring applications.

The Morphology Filter (MF) for ECG strip analysis is intended for a 24h surveillance of the ST segment elevation as well as the rest of the ECG parameters in CCU patients. For testing purpose, the acquired signals were not filtered against net interference (50/60Hz), EMG Low-Pass drift and baseline wander. Other characteristics are: extremely high HR (babies) and low Analog-to-Digital Conversion (ADC) quality. The desired characteristic for extraction from the original signal is its baseline wander (isoelectric reference), so a flat structuring element (SE) is chosen.

If the digitized ECG signal and the chosen SE are denoted with **f** and **k** respectively, in the integer domain:

$$F = \{0,1,...,N-1\} \Leftrightarrow f : F \to I$$
$$K = \{0,1,...,M-1\} \Leftrightarrow k : K \to I$$
$$N > M$$

then formal definitions of the GS MM primitive operators for the *erosion* of f by k and *dilation* of f by k are respectively defined as:

$$(f \theta k)(m) = \min_{n=0,...,M-1} f(m+n) - k(n)$$
$$m = 0,...,N-M$$
$$(f \oplus k)(m) = \max_{n=m-(M-1),...,m} f(n) + k(m-n)$$
$$m = M-1, M, ..., N-1$$

Figure 5 illustrates the shrinking and expanding effects of the applied erosion and dilation on the original signal, respectively (SE is not optimized):

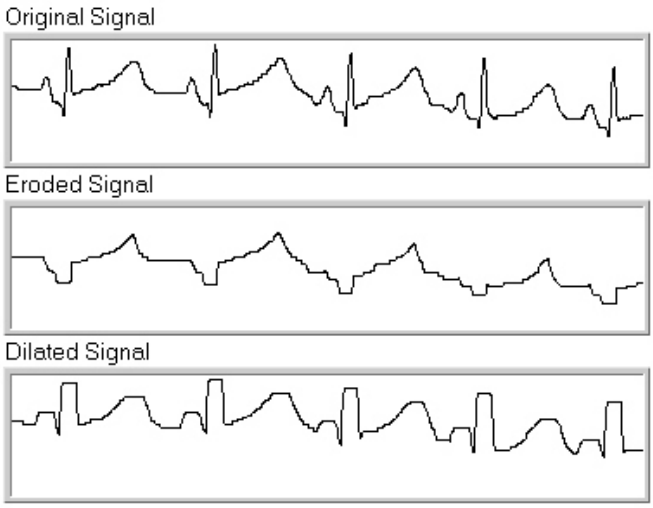

Figure 5. Erosion and dilation of an ECG signal

Accordingly, the GS morphological operators for the *opening* of f by k and *closing* of f by k are defined as consecutive operations of erosion followed by dilation and dilation followed by erosion respectively:

$$f \circ k = (f \theta k) \oplus k$$
$$f \bullet k = (f \oplus k) \theta k$$

Figure 6 illustrates the effects of both when applied on the same original. Obviously, the opening of the signal implies sliding of the SE along it and cutting off its *peaks*; and the closing of the signal implies filling up its *valleys*. The results depend on the size of the SE, thus consecutive application of opening and closing in either order will result in attenuation of parts of the spectrum just like standard Low/High/Band-Stop/Pass filter.

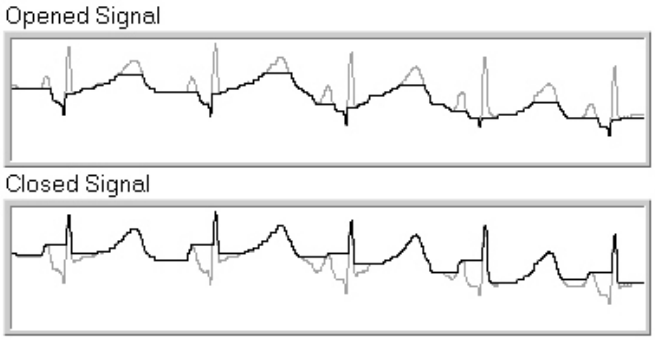

Figure 6. Opening and closing of an ECG signal

Preliminary baseline estimation is the average of both, the opening-closing and closing-opening combinations (Fig 7):

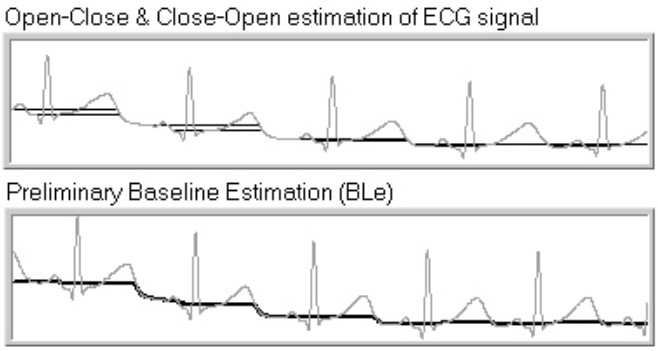

Figure 7. Preliminary BL estimation

Preliminary baseline estimation is needed for the true heart rate determination, after which dominant R/S spikes can be located and the physiological pattern recognition can be performed. Figure 8 presents the Morphology Filter block diagram after which the physiologically based heart rate (HR) determination can be performed in figure 9.

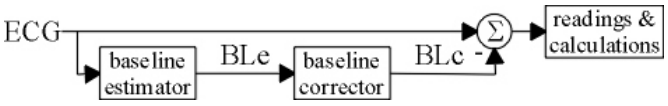

Figure 8. Morphology filter block diagram

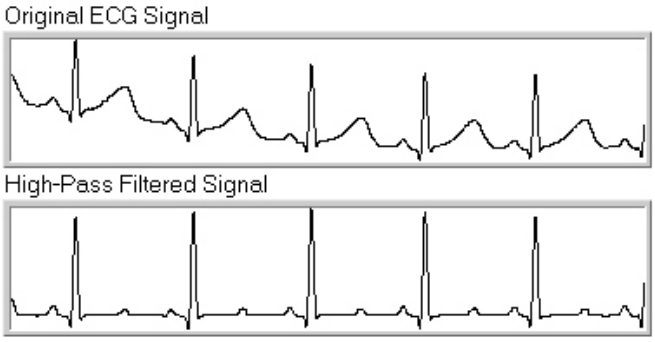

Figure 9. QRS thresholding

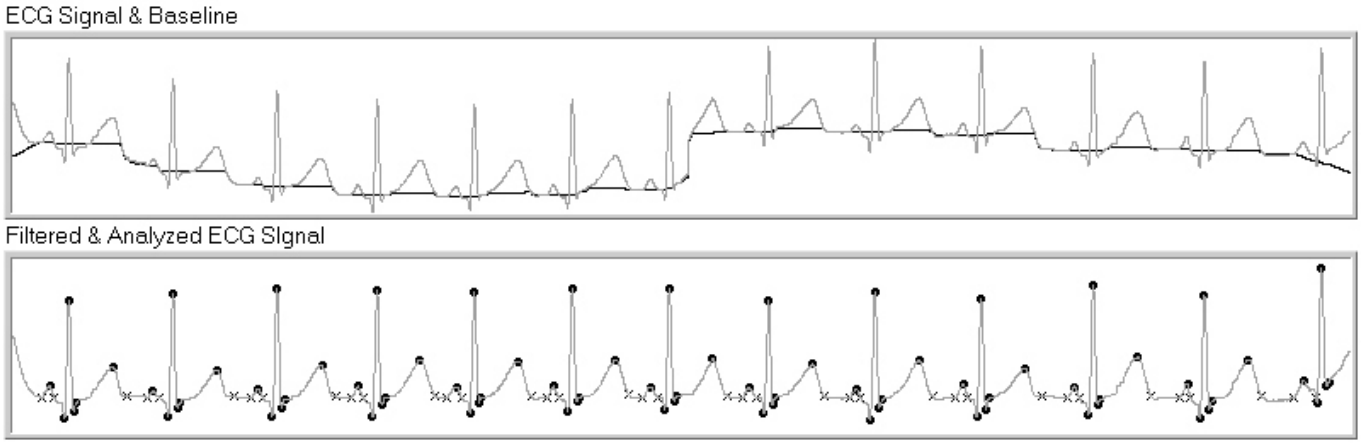

Figure 10. MF analyzed ECG strip (lead DII, 6 sec)

Once the BL is estimated (BLe), using physiological constraints it is possible to perform pattern recognition of the complete PQRST morphology of the ECG signal. Using the recognized P waves it is possible to locate true isoelectric points (P waves starting deflection moments) to correct the BL - only TP segments can be considered isoelectric.

Once the final BL is determined, using the physiological constraints (clinical experience) and the already time-determined ECG morphology, all calculated time segments and voltage deflections can be derived (figure 10).

Relevant amplitudes are read (measured) at the P, R, T and ST positions, and time intervals are calculated for P width, QRS duration, RR interval, PR interval, QT interval and QTc. For each measurement or calculation, calculated are also its mean value, standard deviation and median value within the analyzed ECG strip, thus applying statistical reliability. Using these statistical values for each measurement within the strip (taken from all P-QRS-T complexes) extreme deviations due to artifacts are automatically rejected. The standard deviation can indicate possible arrhythmia detection.

4. CONCLUSION

The two described biomedical applications depict the power of software DSP of physiological potentials without the need of the usual processing hardware.

Both methodologies show the benefit of using the modern software development tools and cheap computers in applications where certain level of "intelligence" is required to overcome the processing difficulties and challenges.

The EEG project would be impossible to realize with the conventional hardware in commercial EEG recorders. The ECG application also works in a domain beyond the capabilities and functionality of commercial ECG recorders.

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