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# Power-line Interference Removal from High Sampled ECG Signals Using Modified Version of the Subtraction Procedure

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***Abstract:*** *The acquired ECG signals are often contaminated by residual Power-line Interference (PLI). A lot of methods, algorithms and techniques for PLI reduction have been published over the last few decades. The so called subtraction procedure is known to eliminate almost totally the interference without affecting the signal spectrum. The goal of our research was to develop a heuristic version of the procedure intended for ECG signals with high Sampling Rate (SR) up to 128 kHz. The PLI is extracted from the corrupted signal by technique similar to second order band-pass filter but with practically zero phase error. The sample number as well as the left and right parts outside the samples belonging to a current sine wave, which is extracted from the contaminated signal, are counted and measured. They are used to compensate the error arising with the shift between the moving averaged free of PLI signal samples and their real position along the linear segments (usually PQ and TP intervals having frequency band near to zero). The here calculated PLI components are appropriately interpolated to 'clean' the dynamically changed in amplitude and position contaminated samples within the non-linear segments (QRS complexes and high T waves). The reported version of the subtraction procedure is tested with 5 and 128 kHz sampled ECG signals. The maximum absolute error is about 20 μV except for the ends of the recordings. Finally, an approach to PLI elimination from paced ECG signals is proposed. It includes pace pulse extraction, signal re-sampling down to 4 kHz and subtraction procedure implementation followed by adding back the removed pace pulses.*

***Keywords:*** *Power-line interference, Subtraction procedure, High sampled ECG signals, Paced ECG signals.*

## Introduction

The acquired ECG signals are often contaminated by residual Power-line Interference (PLI) that cannot be sufficiently suppressed despite the usually high common mode rejection ratio of the contemporary instrumentation amplifiers. This is due to the leakage currents flowing through the patient cable, the unequal electrode impedances and the body [10]. As a result, this PLI is transferred into false differential signal superimposing the heart activity voltage by sinusoidal noise with main frequency of 50 or 60 Hz, possibly accompanied by 3rd and 5th harmonics. DC component and even harmonics are missing as the power generators are made with precision half-wave symmetry.

Generally, the PLI amplitude and frequency are variable. The amplitude changes derive from the spurious electrical circuits. The frequency deviation of the power supply is limited by the standards within ±0.5 Hz. The fluctuations are slow but each difference toward the rated frequency must be canceled immediately once the algorithm is started and currently compensated both for short clinical records and Holter monitoring.

Enormous number of methods, algorithms and techniques for power-line interference reduction has been published over the last few decades. Recently some cancellation techniques were proposed, other were again discussed: traditional and sophisticated notch filters, adaptive and Kalman filtering, Savitzky-Golay smoothing filter, Fast Fourier (FFT) and Discrete Wavelet Transforms (DWT), Recurrent Neural Networks (RNN), modified time-domain subtraction and regression subtraction methods [2-4, 12, 16, 20, 21].

The traditional notch filters affect the ECG spectrum usually defined from 0.3 through 125 Hz. Filter with narrow bandwidth results in lower signal distortions but cannot cope with higher PLI frequency deviations. Kher [12] modified a second-order Finite Impulse Response (FIR) filter introducing pair of complex-conjugated poles to obtain a more selective bandwidth. However, the only figure presented shows reduced amplitudes of several high and steep R waves.

Avendaño-Valencia et al. [2] proposed a tracking method based on Kalman filtering with parameters optimized through genetic algorithms. A clean ECG signal is superimposed by PLI with constant, as well as with variable amplitude and frequency. It is then subjected to the proposed filtration. The results show higher performance compared to the estimation-subtraction method and the non-linear adaptive estimator of non-stationary sinusoids. Actually, a quantitative assessment cannot be made since the differences between the original and the processed signals are not presented.

A trained model based on RNN is used to adapt the amplitude and the phase of a 50 Hz sinusoid to the current PLI waveform [20]. The modified interference is then subtracted from the ECG signal. The results obtained show a 10.5% improved Signal-to-Noise Ratio (SNR). Bhoi1 et al. [4] published a comparative analysis of several filtering techniques applied to 60 Hz PLI suppression in ECG signals.

The statistical evaluation is based on SNR, Mean Square Error (MSE), Root MSE, Peak SNR and peak to peak amplitude. The results suggest that the noise cancellation performance obtained by DWT is better compared to the other techniques. Actually, the ECG analysis is known to be time-amplitude. ECG waves are delineated; the amplitudes, widths, intervals and relationships between them are measured and compared to statistically created sets of data to classify the revealed morphology as normal or pathological heart activity. That is why SNR, MSE and similar measures are not the adequate metrics for PLI suppression assessment.

Yu et al. [21] developed an improved adaptive coherent model, which is able to follow even fast interference changes at the reference input. The algorithm tracks the actual PLI frequency using partial FFT and then adjusts the sampling frequency of the ECG signal at the primary input. The authors illustrate the method by one recording only. They do not discuss the error committed.

The so called subtraction procedure has been developed some decades ago [5, 14]. It was further improved over the years [8, 9, 15, 17-19] and implemented in thousands ECG instruments and computer-aided systems [7, 6]. The subtraction procedure eliminates almost totally the interference without affecting the ECG signal spectrum. Briefly, it consists of the following steps:

(i) comb filter with first zero at 50 or 60 Hz is applied on linear segments (usually PQ and TP intervals having frequency band near to zero);

(ii) the obtained free of interference values are used to compute phase locked interference patterns, saved in a set of corrections;

(iii) they are subtracted from the corresponding samples of the corrupted ECG signal in the adjacent non-linear segments (QRS complexes and high T waves).

The subtraction procedure have been tested carefully by comparing conditionally clean ECG signals with processed contaminated signals, which are obtained by mixing the clean signals with synthesized interference. The difference observed is usually in the limits of ±20 μV, but the real error committed is lower since in fact the conditionally clean signals contain inherent noise. The results obtained do not depend on whether the synthesized interference consists of main frequency only or is mixed by its 3rd and 5th harmonics.

The procedure is extremely efficient even with changing PLI amplitude and frequency. The amplitude variations are taken in consideration by more frequent updates of the correction set using a less restrictive criterion for linear segment detection.

The frequency fluctuations are more difficult to overcome. The early solutions of the problem included small adjustments of the inter-sample distances around their rated value. According to an initial approach [8], each first sample of the PLI period is coupled to a given PL voltage level using Schmidt trigger connected to a secondary winding, the other samples being equally shifted at the rated inter-sample distances. The irregular distance between this sample and the *n*th sample of the previous PLI period results in small additional error, cancelled later on by an improved version: the length of each current period is measured and used for an equal sample allocation during the next period. However, the hardware tracking of the PLI frequency is not available both in battery supplied devices and computer-aided ECG systems, where additionally the analogue-to-digital convertor cannot be ongoing controlled.

A software approach dealing with the PLI frequency deviations was reported by Dotsinsky and Stoyanov [9]. The contaminated signal is band-pass filtered with cut-offs at 48 and 52 Hz. The cross point CP of the interference with the zero line is determined using homogenous triangles defined by the samples located below and above the zero. The CP position on this inter-sample distance is used to calculate the ongoing PLI fluctuation. The contaminated samples are dynamically shifted to turn the variable interference frequency into the rated one. Then, the PLI is removed. The processed samples are shifted back, thus restoring the original timescale.

The PL frequency variation is a special case of the non-multiplicity between the frequency and the Sampling Rate (SR) theoretically leading to not integer number of samples within a rated PL period. As an example, some AHA [1] database recordings, which are digitized with SR = 250 Hz, contain 60 Hz PLI residual components. The problem was overcome generalizing the structure of the subtraction procedure [18, 19]. Three modules are introduced: linear segment detection, PLI extraction and PLI temporal buffer. The basic manipulations are formulated as filters. The linearity is evaluated by the so called D-filter. A K-filter with zero in the PLI frequency (F) and unity gain in 0 Hz removes the PL interference in the linear segments. A set of corrections is obtained by subtracting the filtered samples from the corresponding corrupted samples. The procedure is denoted as (1-K)-filter. The corrections are currently stored in the FIFO temporal buffer to be used in the following non-linear segments. Another B-filter with linear phase response and unity gain in F is introduced specifically for non-multiplicity cases. It extrapolates the stored FIFO values before being used to compensate the amplitude errors introduced by the appeared phase differences.

It is known that a 250 Hz SR would be acceptable for traditional ECG analysis [13]. However, some applications need higher SR. Bazhyna et al. [3] tested the efficiency of PLI suppression methods applied to high resolution ECG recordings with 1 kHz SR and 100 nV/bit resolution.

When pacemaker's pulses have to be detected, an over 5 kHz SR is required. It may reach 16 to 128 kHz [11]. In such cases the ratio SR/F becomes 320 to 2560 for F = 50 Hz that slows down the implementation of the subtraction procedure. To cope with the problem, Mihov [17] developed appropriate changes in the procedure main stages. The efficiency achieved is manifested by ECG recordings with SR = 16 kHz.

The aim of the study is to create a heuristic version of the subtracted procedure intended for ECG signals with SR up to 128 kHz, usually recorded for stimulated heartbeat analysis.

## Materials and methods

### *Data set*

Recordings taken from the AHA database and re-sampled with 5 kHz, as well as paced ECG signals available in the database *PacedECGdb* [11] were mixed by synthesized interferences with 0.5 μV and 1 mV amplitude, respectively and variable frequency with rate of 0.1 Hz/s. The mixed signals are used to develop and test the algorithm and the program written in MATLAB environment. The chosen interference parameters exceed significantly the values encountered in practice but in this way the potential of the subtraction procedure can be better assessed.

### *Brief description of the method*

The PLI elimination from high sampled ECG signals is based on counting the samples within the ongoing disturbing PLI sine waves. The key component of the method is the evaluations of the two out-sample distances located at both ends of the sinusoidal curve. The sum of those lengths is usually lower than the unity accepted as rated inter-sample distance. The obtained fractional number of inter-sample distances/samples inside a wave is further used for 'clean' values calculation in the linear segments. The differences between the corrupted and the 'clean' values called corrections, which are related to the last sine wave, are taken in consideration along the subsequent non-linear segments for denoising the samples according to their dislocation towards the corrections.

The paced ECG signals require an additional approach to the problem. Since the lowest amplitude and duration of pace pulses may reach 250 μV and 100 μs respectively, the pulses have to be extracted and stored before the ECG signal is subjected to PLI elimination. Then the pace pulses are added back to the processed signal.

## *Algorithm description*

### *Preprocessing*

The PLI sine waves are extracted from the contaminated cardiac activity as follows. The corrupted ECG recording (mixed signal) is processed by 1st order band-pass filter with central frequency at 50 Hz and cut-offs at 48 and 52 Hz. The appeared phase shift is compensated applying once more but backwards the filter that corresponds to a second order band-pass filtered signal (*BP* signal) with practically zero phase error.

### *Linear segments*

The ECG linear segments are investigated by means of the linearity criterion

$$D = \text{abs}\{[mix(k+N) - mix(k)] - [mix(k+2N) - mix(k+N)]\} < M,$$

applied over two consecutive periods of F. Here $k$ is the current sample of the mixed signal *mix*, $N$ is the rated number of samples within the period, while $M$ stands for the threshold defined as 100 μV.

The determination of the free of interference values is complicated by variable sample numbers inside the PLI period and by not integer number of inter-sample distances. Besides, the calculated central mean value may do not coincide with any sample position. These problems were overcome as follows.

The border left *lp* and right *rp* inter-sample distances are investigated and computed (Fig. 1):

$$lp = \frac{BP(l)}{BP(l) + \text{abs}\left[BP(l-1)\right]};$$

$$rp = \frac{BP(r)}{BP(r+1) + \text{abs}\left[BP(r)\right]}.$$

Here $l$ and $r$ are current *BP* positions defining $BP(l)$ and $BP(r)$ as the leftmost and rightmost *BP* samples, respectively. The total outside part is $p = lp + rp$, the other inter-sample distances are equated to one, the sample number $N$ inside the wave is equal to $r - l$.

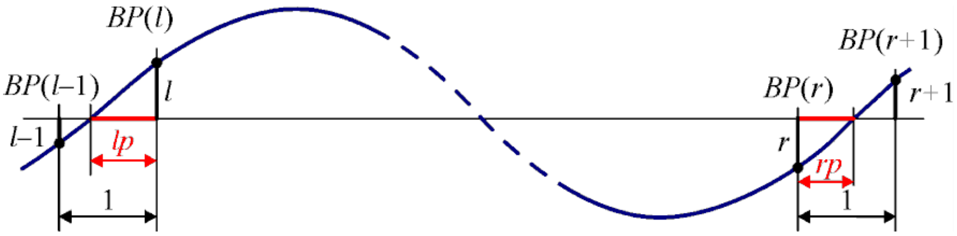

Fig. 1 Determination of the leftmost and rightmost inter-sample distances

The mean total part $p_m = (p_i + p_{i+1})/2$ of two adjacent sinusoids $i$ and $i + 1$ is used to average their corresponding *mix* intervals in sequence. The filtered samples *FS* from the last half of the first interval through the first half of the second one, are calculated dividing the consecutive sums of $N$ *mix* samples $S_N$ by $N - 1 + p_m$ instead of $N$. Thus, the error caused by not integer number of inter-sample distances will be compensated. Since the filtered samples $FS = S_N/(N - 1 + p_m)$ are coupled with the middle of the averaged intervals *mid*, they are additionally shifted to match real sample positions *sp* using the expression

$$FS_c(i) = FS(i-1) + [FS(i) - FS(i-1)]shift,$$

where $shift = sp - mid$ is the difference between *sp* and the middle of the averaged interval *mid*, determined as $mid = (N/2) + 0.5$ in case of integer inter-sample number and $mid = (N + p_m)/2$, otherwise.

The corresponding corrections are $C(i) = mix(i) - FS_c(i)$.

Further on, the two adjacent sinusoids in question are moved forward by one and subjected to the same processing till the end of the linear segment, the set of corrections being each time updated.

*Non-linear segments*

If the linearity criterion is not satisfied, the PLI elimination restarts with the already calculated corrections coupled with the two leftmost *BP* samples $C(i - j)$ and $C(i - j + 1)$ of the last processed interval (Fig. 2).

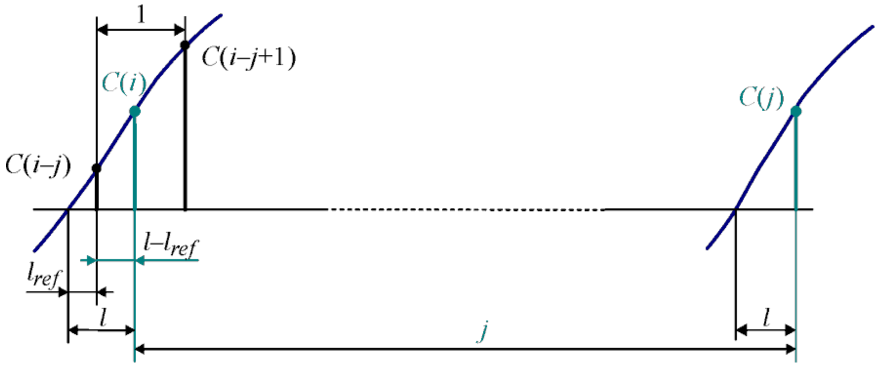

Fig. 2 PLI elimination in non-linear segments

The first new correction is

$$C(i) = C(i-j) + [C(i-j+1) - C(i-j)(l - l_{ref})],$$

where $j$ is the distance between the current and the last processed interval, $l_{ref}$ is the last determined left outside part, $l$ is the current one. Each next correction $C(i + 1)$ is determined by means of the already known $C(i)$.

To avoid calculation errors when the $C(i)$ position is near to the sine wave peak, this correction must be specified through the expression

$$C(i) = 2[C(i-j) - C(i-j-1)].$$

Similar formula is used for corrections with current number higher than *N* of the last processed interval.

## Results and discussion

At the beginning some recordings with SR = 5 kHz were processed. Fig. 3 demonstrates the PLI elimination from the re-sampled AHA 1005d1 signal, which is mixed by F changing from 49 through 51 Hz. The maximum absolute error committed is 17 μV, the first second of which is shown in Fig. 4 in zoomed scale. The error is computed all over the signals except for the ends of the recordings.

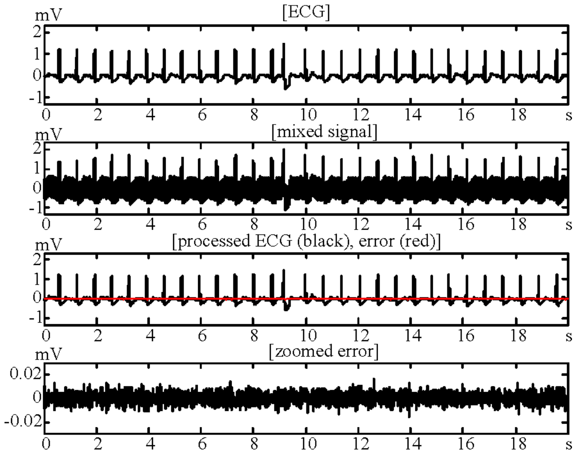

Fig. 3 PLI elimination from AHA 1005d1

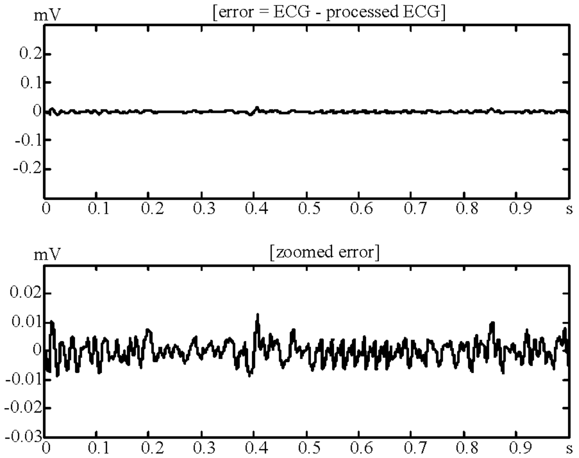

Fig. 4 First second of the recording

As can be seen in Fig. 5, the PLI cannot be suppressed at the beginning of the AHA 1001d1 signal since it starts by QRS complex before being detected any liner segment. The second subplots of Figs. 5 and 6 manifest the lack of phase shift between PLI and *BP* filtered mixed signal.

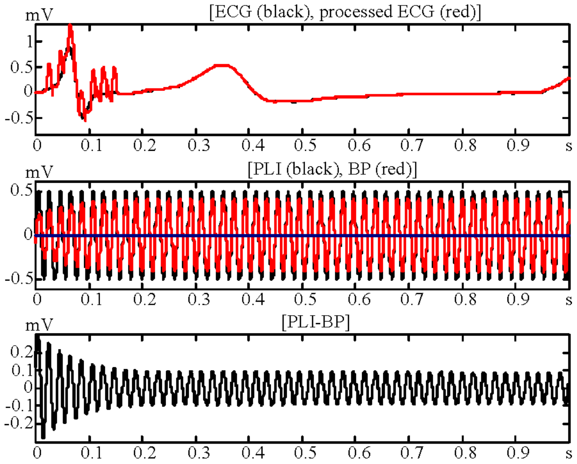

Fig. 5 First second of AHA 1001d1

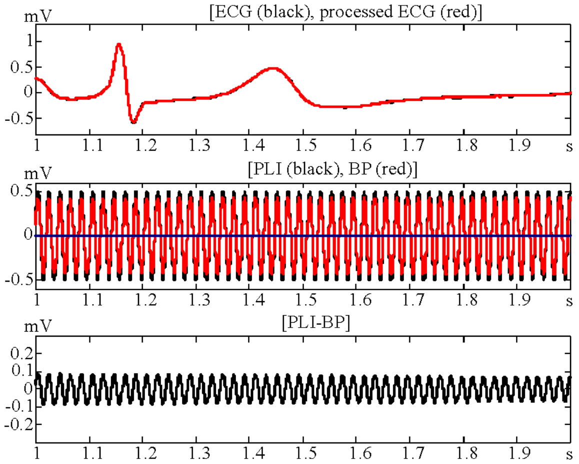

Fig. 6 Last second of the recording

The next tests were performed with paced ECG signals available in *PacedECGdb* [11] comprising a total number of 1404 recordings: 780 representing ‘pure’ ECG with pacing pulses and 624 that contain paced ECG contaminated by tremor, all of them with duration of

10 seconds. The pace pulses are with 7.8 to 102 μs rising edge duration and 102 to 2180 μs pulse duration. The amplitude is usually between 250 μV and 2 mV.

The first subplot of Fig. 7 shows the ECG paced signal p09_16_PacePulse_03_Kp = 0.125 demonstrating fixed-rate ventricular pacing. The pulses, some of them not effective, are with 250 μV amplitude, 23.4 μs rising edge and 211 μs pulse durations The second subplot represents synthesized PLI with SR = 128 kHz and variable PLI frequency F from 45.5 through 50.5 Hz for 5 s. Although the paced signal is announced as ‘pure’, one may observe residual noise in the first subplot, probably some kind of tremor that can corrupt the assessment of the PLI elimination from the mixed signal. Besides, the pace pulses are invisible there but will be totally flatted by any filtering procedure.

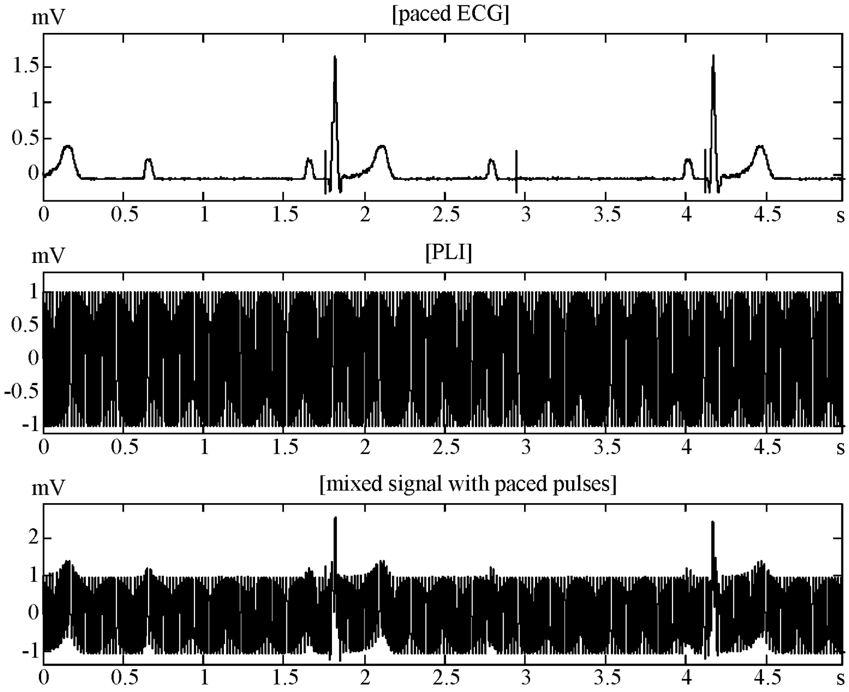

Fig. 7. Contaminated paced ECG signal

Therefore, we proceeded as follows:

- the pace pulses were subtracted from the mixed signal; the corresponding parts were smoothed; the tremor was suppressed by comb filter with first zero at 35 Hz (third subplot of Fig. 8);
- the PLI was eliminated;
- finally the pace pulses were added back.

Some of these steps are illustrated in Figs. 8 and 9. A peak of pace pulse $k$ is detected as sample in the middle of the series of samples $k-3 < k-2 < k-1 < k > k+1 > k+2 > k+3$, if $k$ is higher by 200 μV towards $k-3$ (this value is specified for the processed signal). The pace pulse duration is defined by the sequence $k-5$ through $k+128$ (second subplot of Fig. 8). The mixed signal is smoothed by linear interpolation between the leftmost $k-5$ and rightmost $k+128$ samples, see the third subplot. All 3 extracted pace pulses of the analyzed epoch are displayed at the bottom of the Fig. 8.

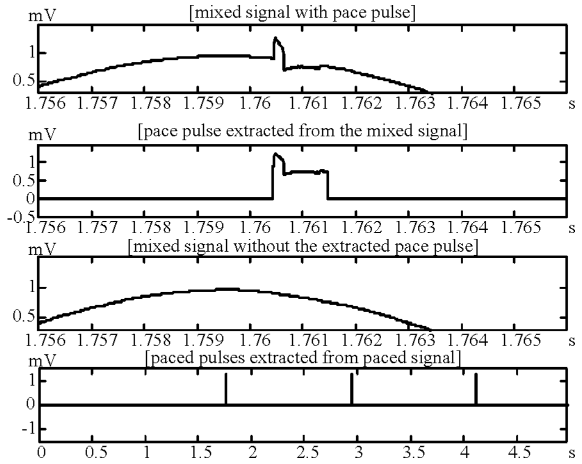

Fig. 8 Extraction of pace pulses

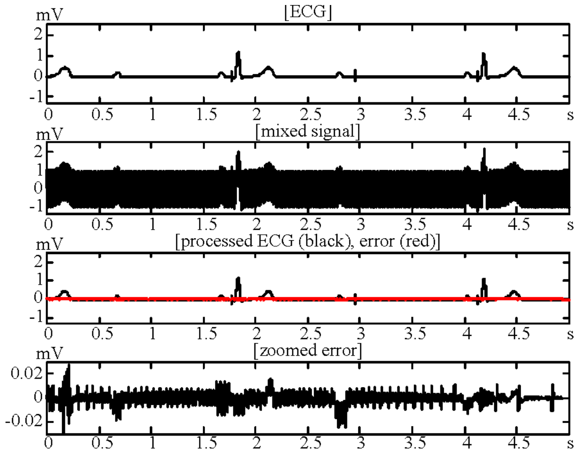

Fig. 9 Processing of the paced ECG signal

The mixed signal is subjected to the subtraction procedure (Fig. 9). The result is compared to the input ECG signal with suppressed tremor (the third subplot). The error committed is correctly evaluated as about 20 μV, see the forth subplot. The last two Figs. 10 and 11 exhibit this error in zoomed scale along the 4th and 5th seconds of the recording.

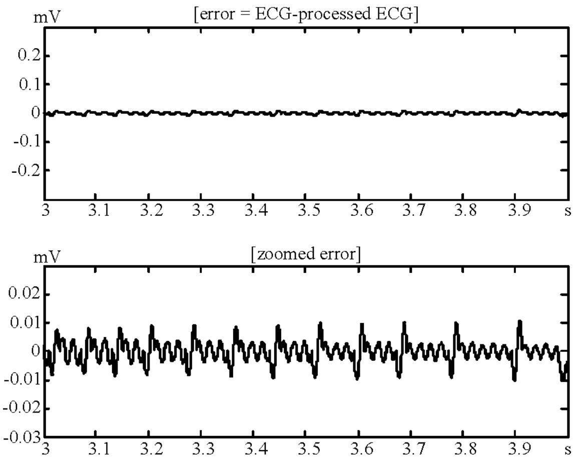

Fig. 10 Forth second of recording

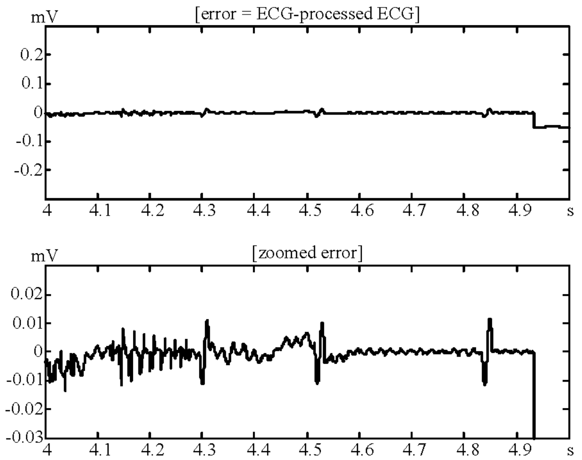

Fig. 11 Last second of the recording

The real sequence of steps proposed for removing the PLI from paced ECG signals, usually sampled with 128 kHz, is shorter than the above pointed out. The pace pulses are extracted from the contaminated (mixed) signal after that their intervals are smoothed. The mixed signal is re-sampled down to 4 (16) kHz and subjected to the subtraction procedure. The processing time is significantly reduced while at the same time the processed ECG keeps all useful information. A SR lower than 2.5 kHz will unacceptably reduce the PLI removing accuracy.

## Conclusions

The developed version of the subtraction procedure intended for high sampled signals is based on the ongoing analysis of PLI sine waves available after *BP* filtration of the contaminated ECG signal with negligible phase shift. The calculated sample number, as well as the leftmost and rightmost parts outside the samples are successfully used for PLI removing both in linear and non-linear segments. The maximum absolute error obtained with 5 and 128 kHz sampled ECG signals is about 20 μV except for the ends of the recordings.

The proposed approach to PLI elimination from paced ECG recordings (usually sampled with 128 kHz or at least 16 kHz) includes pace pulse elimination, signal re-sampling down to 4 kHz and implementation of the subtraction procedure, followed by adding back the pace pulses.

## References

1. AHA database, http://www.ecri.org/.
2. Avendaño-Valencia L., E. Avendaño, J. M. Ferrero, G. Castellanos-Domınguez (2007). Improvement of an Extended L.D. Kalman Filter Power Line Interference Suppressor for ECG Signals, Computers in Cardiology, 34, 553-556.
3. Bazhyna A., I. I. Christov, A. Gotchev, I. K. Daskalov, K. Egiazarian (2003). Powerline Interference Suppression in High-resolution ECG, Computers in Cardiology, 30, 561-564.
4. Bhoi A. K., K. S. Sherpa, B. Khandelwal (2019). Comparative Analysis of Filters for Cancellation of Power-line-interference of ECG Signal, Int J Bioautomation, 23(3), 259-282.
5. Christov I., I. A. Dotsinsky (1988). New Approach to the Digital Elimination of 50 Hz Interference from the Electrocardiogram, Med Biol Eng Comput, 26, 431-434.
6. Daskalov I. K., I. A. Dotsinsky, I. I. Christov (1998). Developments in ECG Acquisition, Preprocessing, Parameter Measurement and Recording, IEEE Eng Med Biol, 17, 50-58.
7. Dotsinsky I. A., I. I. Christov, C. L. Levkov, I. K. Daskalov (1985). A Microprocessor-electrocardiograph, Med Biol Eng Comput, 23, 209-212.
8. Dotsinsky I. A., I. K. Daskalov (1996). Accuracy of the 50 Hz Interference Subtraction from the Electrocardiogram, Med Biol Eng Comput, 34, 489-494.
9. Dotsinsky I., T. Stoyanov (2008). Power-line Interference Removal from ECG in Case of Power-line Frequency Variations, Int J Bioautomation, 10, 88-96.
10. Huhta C., J. G. Webster (1973). 60 Hz Interference in Electrocardiography, IEEE Trans Biomed Eng, 20, 91-100.
11. Jekova I., V. Tsibulko, I. Iliev (2014). ECG Database Applicable for Development and Testing of Pace Detection Algorithms, Int J Bioautomation, 18(4), 377-388.
12. Kher R. (2019). Signal Processing Techniques for Removing Noise from ECG Signals, J Biomed Eng, 11-19.
13. Kwon O., J. Jeong, H. B. Kim, I. H. Kwon, S. Y. Park, J. E. Kim, Y. Choi (2018). Electrocardiogram Sampling Frequency Range Acceptable for Heart Rate Variability Analysis, Health Inform Res, 24(3), 198-206.
14. Levkov C., G. Michov, R. Ivanov, I. Daskalov (1984). Subtraction of 50 Hz Interference from the Electrocardiogram, Med Biol Eng Comput, 22, 371-373.
15. Levkov C., G. Michov, R. Ivanov, I. Daskalov, I. Christov, I. Dotsinsky (2005). Removal of Power-line interference from the ECG: A Review of the Subtraction Procedure, BioMed Eng OnLine, 4:50.
16. Li Q., C. Rajagopalan, G. D. Clifford (2014). A Machine Learning Approach to Multi-level ECG Signal Quality Classification, Comput Methods Programs Biomed, 117(3), 435-447.
17. Mihov G. (2018). Subtraction Procedure for Power-line Interference Removal from ECG Signals with High Sampling Rate, Int J Bioautomation, 22(2), 147-158.
18. Mihov G., I. Dotsinsky (2008). Power-line Interference Elimination from ECG in Case of Non-multiplicity between the Sampling Rate and the Power-line Frequency, Biomedical Signal Processing and Control, 3, 334-340.
19. Mihov G., I. Dotsinsky, Ts. Georgieva (2005). Subtraction Procedure for Power-line interference Removing from ECG: Improvement for Non-multiple Sampling, J Med Eng Technol, 29(5), 238-243.

20. Qiu Y., K. Huang, F. Xiao, H. Shen (2017). Power-line Interference Suppression in Electrocardiogram Using Recurrent Neural Networks, 10th International Congress on Image and Signal Processing, BioMedical Engineering and Informatics (CISP-BMEI), Shanghai, 1-6, doi: 10.1109/CISP-BMEI.2017.8302231.
21. Yu Ch., G. Li, L. Lin, S. C.-Y. Lu (2005). The Realization of Tracking Power-line Interference Adaptive Coherent Model Based on Part FFT, Journal of Physics: Conference Series, 13, 7th International Symposium on Measurement Technology and Intelligent Instruments, 274-279.

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