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Classic, adaptive filtering techniques in the ECG signal enhancement

Streszczenie. *Artykuł przedstawia wyniki prac w zakresie eliminacji zakłóceń z sygnału elektrokardiograficznego (EKG). Zakłócenia te charakteryzują się zmiennością zarówno w czasie jak i w częstotliwości. Dodatkowo własności widmowe pokrywają sie z własnościami użytecznego sygnału pomiarowego. Fakt ten jest bardzo niepożądany w aspekcie skutecznej analizy i diagnostyki sygnałów EKG. Zatem z uwagi na różnorodność i zmienność charakteru zakłóceń filtracja adaptacyjna wydaje się być odpowiednim narzędziem skutecznie poprawiającym jakość sygnału.*

Abstract. *The paper presents Authors' investigations in the field of the Electrocardiography (ECG) signal noise reduction. The distortions of ECG signal recordings are changing both in time and frequency and their frequency properties overlap the frequency spectrum of the pure ECG signal. This effect is very unfavourable in terms of the effective ECG signal analysis and diagnostic. As the properties of the ECG signal distortions are nonstationary, adaptive techniques for their rejection seems to be adequate in the purpose. (**Zastosowanie klasycznych technik filtracji adaptacyjnej w przetwarzaniu sygnałów elektrokardiograficznych**).*

Słowa kluczowe: przetwarzanie sygnałów EKG, redukcja zakłóceń filtracja adaptacyjna.
Keywords: ECG signal processing, noise reduction, adaptive filters.

Introduction

ECG signal is the one of the highest factor of importance from the medical diagnostic point of view. Unfortunately the recording process is affected by the quite wide range of disturbances. Their sources are: patient itself and his close environment. Generally, there are three main groups of the distortions that can worse final signal quality: base line wander (patient's movement and breathing, non ideal signal paths and connections), power system interferences (50 or 60 Hz), high frequency (radio) interferences and muscle tremors. All of these sorts of noise are variable both in time and frequency domain.

The main goal that Authors would like to achieve is to design relatively low computational load algorithm that would be able to work in the ECG recorders devices. Commonly these devices are not equipped with PC class CPU but with a controller that is much less productive. On the other hand there are strong obvious medical demands regarding the form of the presented ECG signal. It must be real time, cleared, free from noise and without filtering deformations. Fulfilment of all listed requirements is of the fundamental importance to medical personnel. It is because of that the final diagnosis and undertaken medical treatment is fully dependent on the quality of the gathered input data.

Background

From the diagnostic point of view it is desired to dispose of the pure signals. It is essential property required in the manual (performed by a physician) or automated (computer aided) analysis. Diagnosis quality is very sensitive to the noise content of the signal being investigated. That is why it is very important to clean out possibly all kind of distortions prior to ECG analysis and identification. Obviously, the properties of the ECG disturbances are not constant so the methods used for their elimination should also adopt, identify and remove the ECG distortions. The nature and origin of ECG signal disturbances is complex and the adaptive method are more demanding in terms of circuit and computational complexity. That is the reason that classic, simpler techniques of filtration are commonly used (ie. FIR and IIR filters). They are less demanding and do not require any additional input signal. These features are especially important as DSP procedures are applied in the lower computing power environment. The filtration procedure would be easy as it would be applied to the signal consisting of a fundamental signal and the distortion, both stationary and distinctly separated one from another.

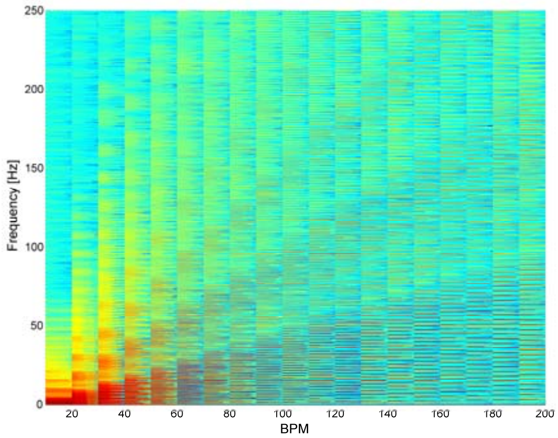

Fig 1. Artificial ECG signal frequency spectra for a wide range of BPM. HP arbitrary waveform generator was used as a ECG signal source

Unfortunately none of the useful properties mentioned above are satisfied in the ECG signal recordings. Fundamental ECG signal and its distortions both are not stationary. Figure 1 presents frequency spectra (vertical lines) for different heart rates (BPM).

It clearly shows the difference of the spectra forms when just only one parameter varies. The analysed artificial signal was periodic, what must not be assumed in real signals analysis. This consequence makes frequency spectra variable in time. What is more, the frequency spectra of the distortions are variable and overlap frequency spectrum of the ECG signal and it is impossible to draw a distinct border between desired and useless components. Still, there is a strong need is to remove as much as possible noise content without excessive deformation of the essential ECG signal. That is why Authors decided to implement adaptive filtration scheme to take over the control of the filtration quality following the noise change.

Approach

Authors utilise adaptive filtration scheme based on least mean squares adaptive filter algorithm. It appears to be most adequate in the ECG signal enhancement process. As there are many different noise sources that independently distort the input ECG signal there should be a separate filter used to remove particular kind of noise. In ECG signal enhancement there are three different kind of distortions taken into account. In addition there are two filter approaches concerning the input and desired signal configurations.

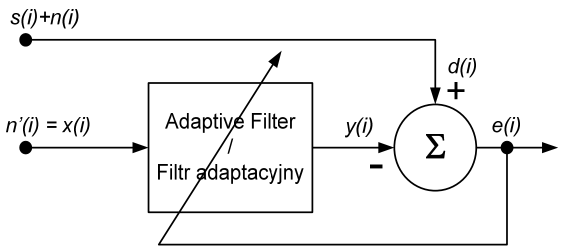

Fig 2. Classic block diagram of the circuit for the adaptive noise rejection. Used symbols are: $s(i)$ - measurement signal, $n(i)$ - noise signal, $d(i)$ - desired signal, $n'(i)$ - signal correlated to $n(i)$, $x(i)$ - adaptive filter input, $y(i)$ - adaptive filter output, $e(i)$ - error signal

The classic, adaptive filter approach requires dedicated input signal configuration (fig. 2). Additional input provides information on signal distortion that is to be removed.

Authors took into account several different setup circuits for the filter input configuration during the research. The first one was classic with two inputs: noisy signal input and noise correlated input (amplitude and phase modification for the periodic and low frequency distortions; amplitude and time delay for the random noise distortions). This variant assumes additional hardware circuit for selected noise acquisition. It would be especially simple for power line interference acquisition. Nevertheless at last it increases the total cost of the device and in terms of economic aspects is not warm welcomed. Then, the second verified case involved only simple time delay between input and desired signal filter inputs. Additionally there was passband FIR filter alternatively added for the noise extraction at the adaptive filter input $x(i)$.

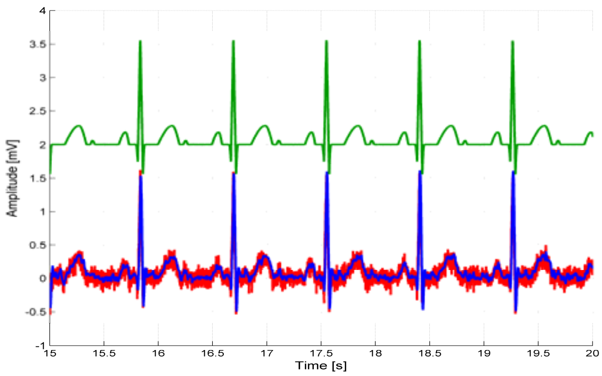

Fig 3. Sample results of the random noise rejection (original ECG signal – green, noisy ECG signal – red, filter output - blue)

Results and conclusions

Three types of fundamental distortions were investigated. For the wide frequency distortion noise several cases were tested with the SNR in range of 10-20 dB. Adaptive filtration performed, resulted in up to 10 times noise attenuation. One would expect to get better results but random noise overlaps the useful signal frequency content so intensive noise cancelation will also deteriorate the meaningful and useful signal. What is more, better attenuation parameters would probably require more computational effort.

Low frequency noise filtration produced interesting outcomes. Relatively high amplitude distortions were efficiently removed, but there were some local output signal unacceptable deformations (e.g. between 0,5 and 1 s in the fig. 4). It is a task for the continued research.

Best results were obtained for power line cancelation. Interferences were minimized just after 0.2s (fig. 5). Experiments were performed for the continuously changing power line frequency varying from 50 to 60 Hz, still giving satisfactory results.

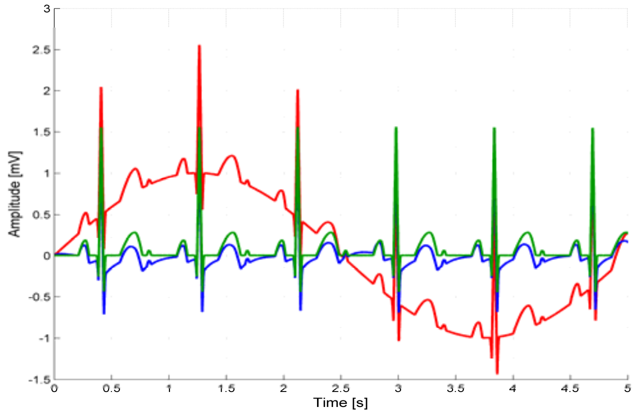

Fig 4. Sample results of the baseline wander rejection (original ECG signal – green, noisy ECG signal – red, filter output - blue)

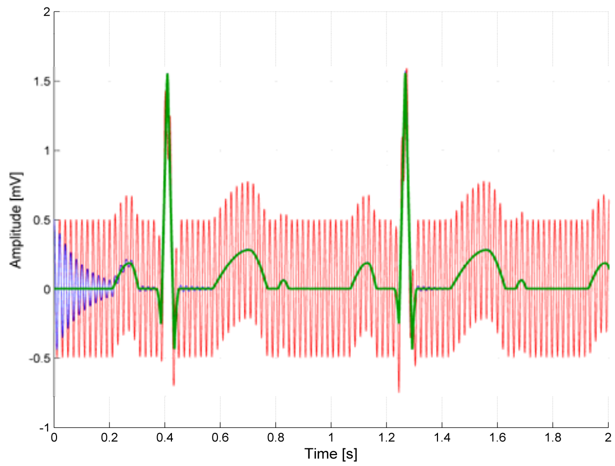

Fig 5. Sample results of the power system interference rejection (original ECG signal – green, noisy ECG signal – red, filter output – blue form 0,4 s the same as original input)

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