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Spectral Analysis of ECG Signal for Detection of Power Line Interference

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Abstract - ECG signal are usually contaminated by noise which can be within the frequency band of interest. This noise arises due to interference between ECG equipment and electromagnetic field of power lines. This contamination can lead to imprecise measurements of the ECG wave durations and amplitudes. Therefore, the accuracy of the ECG analysis can be significantly reduced. In this paper we have examined the possibility to use Welch method to perform spectral analysis of ECG signal for correct diagnosis.
Keywords - Electrocardiograph, Nonparametric, Welch's method, Power spectral density.

I. INTRODUCTION

Recordings are often contaminated with power-line interferences of different characteristics. These interferences need to be detected prior to most filtering techniques to minimize the risk of signal distortion. Spectrum estimation methods are used to extract relevant information from a signal by transforming it. Nonparametric power spectrum estimation methods can be used to obtain the relevant information from a signal especially when the noise characteristics are unknown [1].The theoretical foundation is the ECG's Power Spectral Density (PSD). In the presence of PLI the PSD consists of a part caused by the ECG itself and a part caused by PLI. The latter part produces narrow peaks at corresponding frequency. The common nonparametric power spectrum estimators available in the literature: the periodogram [2], the modified periodogram [3] and Welch's method [6]. However, all these nonparametric power spectrum estimators are modifications of the classical periodogram method introduced by Schuster [7]. Using periodogram method, in practice the shape of the calculated PSD is also influenced by spectral leakage and windowing. Thus, the PSD is calculated using Welch's method with an appropriate window size balancing between variance reduction and resolution.

The length of the observed ECG record or the observed interval must be chosen to enable a variance reduced PSD estimation. This is achieved by averaging the PSD in minimal 10 overlapping intervals. The chosen window length of each interval has to enable an accurate frequency resolution, to facilitate a decision between 50 Hz peaks.

This paper is organized such that the analytical aspects for non-parametric method, i.e., periodogram and Welch's method [10] are presented at first in order to outline how this method can be applied. It presents a scheme to detect PLI in ECG signal using Welch method.

II. WELCH METHOD

This method is based on the computation of modified periodogram of L overlapping segments of length-N input samples and then averaging these L periodograms. Assuming the infinite length random signal and windowed by length N window sequence $w[n], 0 \le n \le N-1$, where $w[n]$ is the nonrectangular window sequence.

Assuming the overlap between the adjacent segments be r samples. Then the windowed lth segment is given as

$$y^{(l)}[n] = x[n+lr].w[n], \qquad (1)$$

where $0 \le n \le N-1$, $0 \le l \le L-1$

Using Eq. (4) the periodogram of the lth segment can be given as

$$\hat{P}_{xx}^{(l)}(f) = \frac{1}{f_s CN} | F^{(l)}(f) |^2 \qquad (2)$$

The average of all L periodograms, i.e., Welch estimate $\hat{P}_{xx}^{W}(\omega)$ is given as

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$$\hat{P}_{xx}^{W}(f) = \frac{1}{f_s L}\sum_{l=1}^{L-1}\hat{P}_{xx}^{(l)}(f) \qquad (3)$$

The expected value which gives the bias is given as

$$E\{\hat{P}_{xx}^{W}(f)\} = \frac{1}{f_s LC}\int_{-f_s/2}^{f_s/2} P_{xx}(\rho)\,|W(f-\rho)|^2\, d\rho \qquad (4)$$

where L is the length of the overlapping data segments and C is the normalization constant, $W(f)$ is the DTFT of the nonrectangular window sequence $w[n]$.

The variance of Welch estimate is reduced by a factor of L [cf. Eq. (3)], assuming that L periodogram estimates are independent of each other. For a fixed length input sequence, the overlapping segments L can be increased by decreasing the window length N which decreases the resolution. Moreover, the variance is inversely proportional to the number of segments L whose modified periodograms are being averaged.

For the fixed length data record the bias of Welch estimate is larger than that of the Periodogram as L< N. the variance is inversely proportional to the number of segments L whose modified periodograms are being averaged.

III. ARTIFICIAL POWER LINE INTERFERENCE

In general a PLI can be described as a Cosine or Sine function

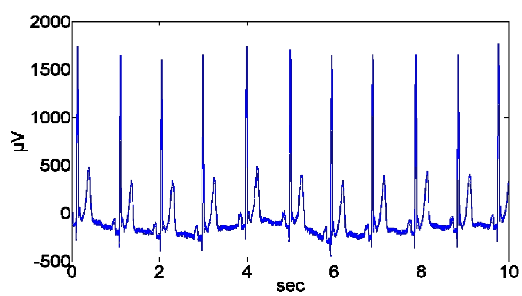
$$e_{PLI} = A\cos(2\pi h_n)$$

with A the amplitude of the PLI and h_n the frequency of the harmonic interference (50, 60, 100, 120, etc). The analysis of the strength measure is performed on a logarithmic scale of the PSD. So with linear increasing amplitude factor of the PLI the obtained strength measure will be mono-tonic increasing as well, but with a more logarithmic behavior. Interferences with a strength measure smaller than the defined threshold are not considered. So it is important to know, when the amplitude of the PLI causes an interference strength measure bigger than this threshold. The minimal detectable amplitude is depending on the sampling-frequency, the signal length and most of all on the shape of the ECG part in the PSD. The threshold value ~1.5 mv is used.

IV. RESULTS

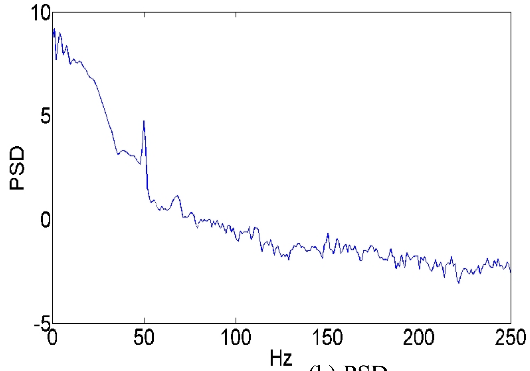
We have used test ECG signals with no PLI and these signals are disturbed with artificial PLI of different amplitudes A and frequencies f_n. The sampling frequency of all records is 500 Hz.

In figure 1, a test ECG signal with PLI is shown. Figure 2 gives the power spectral density using Welch method which detects 50 Hz PLI with a strength measure of 2.56.



(a) Test signal

Figure1. Test signal with 50 Hz PLI



(b) PSD

Figure2. Detected 50 Hz PLI with a strength measure of 2.56 using Welch method

V. CONCLUSIONS

Detection of power line interference is required for correct diagnosis of ECG. In case of Welch method, there is a reduction in spectral leakage that takes place through the side lobes of the data window used. Use of nonrectangular windows has the effect of reducing the spectral leakage. It can also be considered as consistent estimator of PSD as there is monotonic decrease in variance of the PSE with increase of the fraction of overlap. By the reduction of variance true spectral features can be distinguished, but if the variance is further reduced by increasing the fraction of overlapping, there will be loss of resolution. Hence, Welch method can be used for PLI detection.

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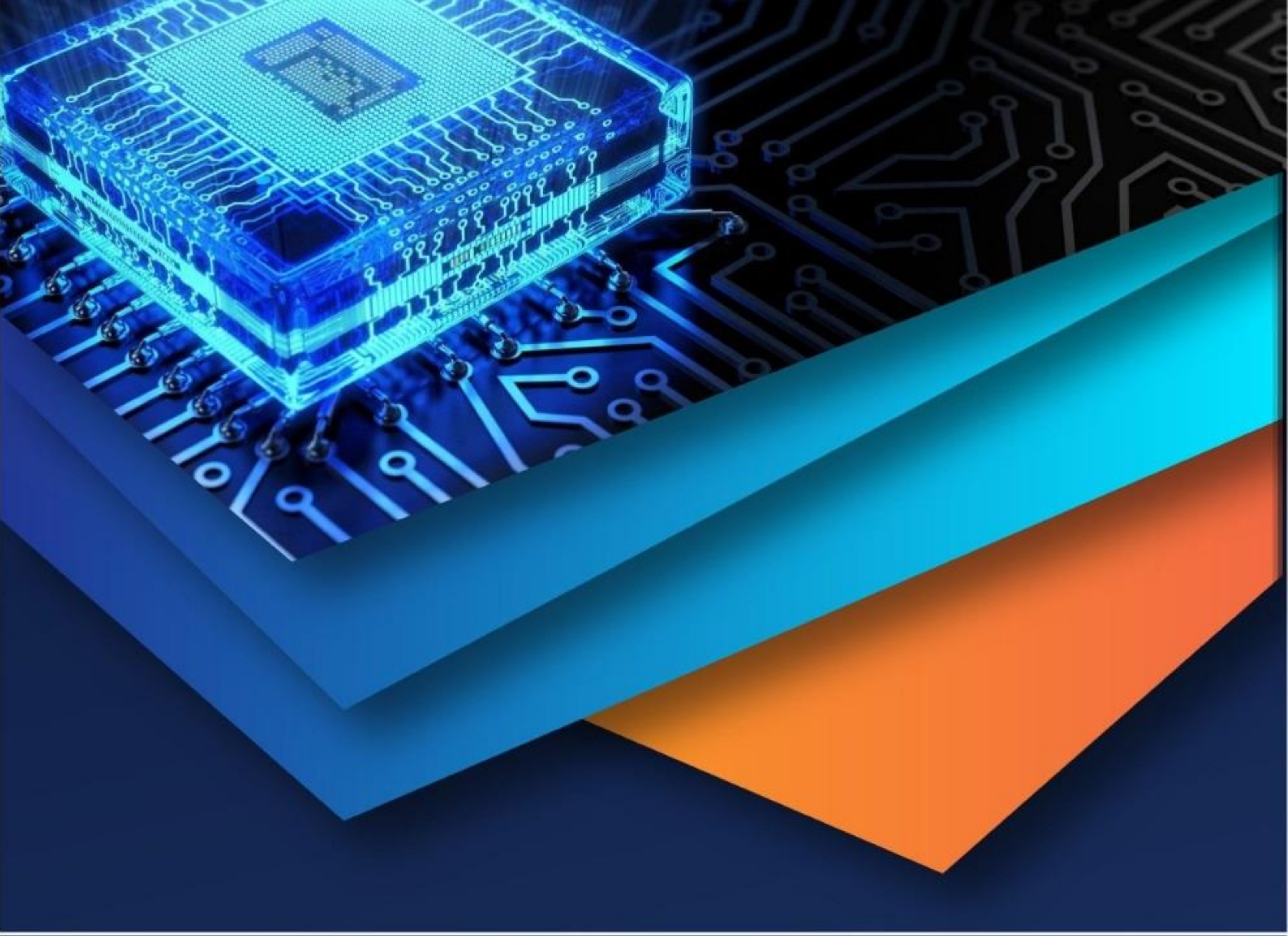

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