ADAPTIVE POWER LINE INTERFERENCE CANCELLER: A SURVEY

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ABSTRACT

In this paper, we present a survey on implementation of adaptive power line interference canceller for ECG signals and recommends Least mean-square (LMS) algorithm for implementation of adaptive power line interference canceller using FPGA. Notch filters and adaptive interference cancellers are proposed in literature for power line interference canceller. Notch filters are ineffective, whenever the power line frequency is not stable or not accurately known, a mismatch between the suppression band and the power line frequency might lead to inadequate reduction of the power line interference therefore adaptive interference cancellers are beneficial. LMS algorithm is commonly used on adaptive filtering since it enables the design of modular systolic architectures. Adaptive interference cancellers are implemented using general-purpose microcontrollers or digital signal processors. These solutions are not optimum since they have low processing speed and sequential execution due to the fact that adaptive cancellers are implemented with a software program. Another solution is the implementation of the adaptive controller with field-programmable gate array (FPGA). The fundamental advantage that FPGAs offers is the parallel implementation of ECG signal processing algorithms without losing processing speed. It also provides additional control and management features in monitoring the ECG process. Use of systolic architectures in the implementation of LMS algorithm results in reduced area and high speed of operation.

KEYWORDS: *Adaptive Interference Canceller, FPGA Implementation, LMS.*

I. INTRODUCTION

An ECG signal is basically an index of the functionality of the heart. Power line interference may be significant in electrocardiography. Power line interference coupled to signal carrying cables is particularly troublesome in medical equipment such as electrocardiograms (ECGs). Cables carrying ECG signals from the examination room to the monitoring equipment are susceptible to electromagnetic interference (EMI) of power frequency (50 Hz or 60 Hz) by ubiquitous supply lines and plugs noise that sometimes the ECG signal is totally masked. For a high quality analysis of the electrocardiogram (ECG), the amplitude of the power line interference should be less than 0.5% of the peak-to-peak QRS amplitude. ECG signals polluted by power line noise of relatively large amplitude were the frequency of power line interference accurately at 50 Hz or 60 Hz, a sharp notch filter would be able to separate and eliminate the noise. Filtering such EMI signal is a challenging problem given that the frequency can vary about fractions of a Hertz, or even a few Hertz and frequency of the time-varying power line signal lies within the frequency range of the ECG signal. There are some other technical difficulties involved, the most important of which is the low sampling frequency at which the ECG signals are taken and the low computational resources available at the level of the apparatus [1].

The frequency spectrum of this signal spans from near dc frequencies to about 100 Hz. The sampling frequency in most ECG devices is 240 Hz or 360 Hz. Therefore, the spectrum can theoretically include frequencies from zero to 180 Hz. ECG signals are severely distorted by power line noise. Therefore sharp notch filter is essential to separate and eliminate the noise. The notch filter is ineffective because frequency of power line is unstable and varies about fractions of a Hertz, or even a few Hertz. The sharper the notch filter is designed, the more inoperative, or rather destructive, it becomes if any change in the frequency of the power line occurs, turning the notch filter into a band-stop filter by widening its rejection band, and thereby accommodating frequency variations, does not offer any better solution since it will undesirably distort the ECG signal itself. The frequency of the power grid is usually taken as being constant when conventional EMI filters for ECGs are designed. In such arrangements, the system is very delicate with respect to power frequency variations and can become completely inoperative [1]. One of the possible alternatives to take frequency variations into account is the use of an external reference power line signal. This technique, available by the use of adaptive filters only, is reported to present serious practical difficulties and is difficult to implement. For this reason, other methods, usually very complex and inflexible, are constantly being proposed. An ideal EMI filter for ECG should act as a sharp notch filter to eliminate only the undesirable power line interference while automatically adapting itself to variations in the frequency and level of the noise. This adaptation must be done very quickly so as to keep the signal clean all the time. It is supposed to be able to work in low information background, namely that dictated by low sampling frequency, and must be robust with respect to variations in its internal as well as external conditions. An ideal power line interference suppression method should eliminate the power line interference while preserving the signal of interest. For this purpose, notch filters and adaptive interference cancellers are two different approaches which can be used. Notch filters reduce the power line interference by suppressing predetermined frequencies. Usually, an infinite impulse response (IIR) filter is adopted. The magnitude and phase spectrum of the ECG signal are less affected by narrow suppression band filters. Therefore, the suppression band of the notch filter should be as narrow as possible. However, this leads to problems whenever the power line frequency is not stable or not accurately known, a mismatch between the suppression band and the power line frequency might lead to inadequate reduction of the power line interference.

Adaptive interference cancellers have a general structure as shown in Fig. 1 [2], that consist of the interference signal, the signal of interest, and the corrupted signal. The interference can be represented as a known function of the interference parameter vector. If input signal is a sinusoid, for instance, the interference parameter vector may contain its amplitude and phase. An interference estimate is internally generated as a function of the estimated parameter vector. The error signal is the difference between the corrupted signal and the estimated interference, and it is processed by an adaptation sub-scheme in order to find an estimate of frequency. The sub-scheme behavior depends on the adaptation constant vector. It is common practice to assume and to be uncorrelated and configure the adaptation sub-scheme such that the mean-squared error (MSE) is minimized. This is referred to as least mean square (LMS) estimation. After convergence, the error is an estimate for the signal of interest which is the ECG signal [2].

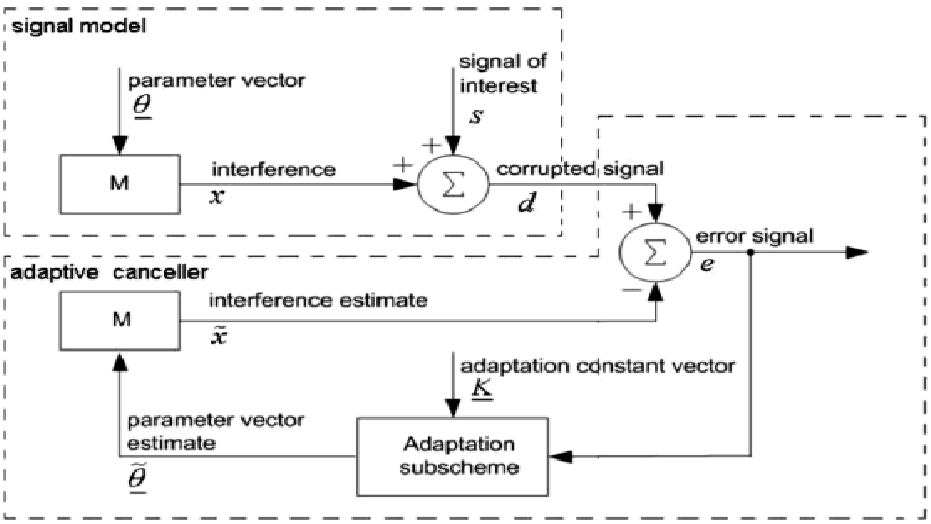

Figure 1 General Structure of Adaptive Interference Canceller

To implement the adaptive canceller, different solutions are available. For example, one can use general-purpose microcontrollers or digital signal processors. The microcontroller's architecture works in sequential mode instead of parallel mode, and therefore, the speed is lower. Another solution is the implementation of the adaptive controller with field-programmable gate array (FPGA). This FPGA implementation offers several advantages:

- FPGAs are low-cost devices, and the development system works on personal computers where high processing speed is reached due to the optimized specific design.
- The use of FPGAs offers the parallel ECG signal processing advantage without losing processing speed, while adding control and management features in monitoring the ECG process.

In this way, better performance in terms of processing speed than the ones with general-purpose microprocessors or digital signal processors can be achieved [3].

In this paper, we present a survey on implementation of adaptive power line interference canceller for ECG signals and recommends Least mean-square (LMS) algorithm for implementation of adaptive power line interference canceller using FPGA. This section introduces the use of power line interference canceller in ECG signal processing and highlights the advantages of FPGA. Section II provides the detail literature survey and section III highlights the advantages of implementation of power line interference canceller using FPGA. Section IV introduces to the FPGA design flow and finally conclusion is provided in section V.

II. LITERATURE SURVEY

Power line interference (either 60 Hz or 50 Hz) is a significant source of noise in biomedical signal recording [4]. Elimination of power line interference in the ECG by adaptive filtering, using an external reference signal, was first proposed by Widrow [5]. A system for adaptive elimination of line interference, using an external reference, in diagnostic ECG's has also been reported by Ider and Koymen [6]. It is often desirable, or necessary, to reduce power line interference when an external reference is not available. Ahlstrom and Tompkins [7] reported on an adaptive 60-HZ filter for ECG signals that used an internally generated reference signal. Glover [8] showed that Ahlstrom and Tompkins' filter is approximately equivalent to a nonadaptive, second order, notch filter, implying that the performance of a nonadaptive 60-Hz notch filter and an adaptive 60-Hz notch filter with an internally generated reference is equivalent.

As the transient response time of a notch filter increases, the rejection bandwidth of the filter decreases. If an adaptive 60-Hz notch filter is adjusted to adapt quickly to changes in noise, the rejection bandwidth will be wider, and there will be more attenuation in signal components at frequencies close to 60 Hz. Conversely, if the bandwidth of the notch filter is reduced, the transient response time will increase, and the filter will adapt more slowly to changes in noise. Because the transient behaviour of Ahlstrom and Tompkins' filter is different from the transient behaviour of a nonadaptive notch filter, it is hard to predict how well the filters will track changes in noise in an actual ECG signal. It is also hard to predict the relative distortion that the two filters will introduce in a typical ECG signal. Compared to a nonadaptive implementation of a power line frequency filter, the Ahlstrom and Tompkins' adaptive filter with an internally generated reference is less complex, produces less distortion in a typical ECG, and is more effective in removing low level 60-Hz noise. These performance differences are due primarily to the different transient behaviour of the two filters.

The adaptive Lu-wave device can automatically track the frequency change frequency interference, literature [9] proposed single-channel devices with wave frequency estimation which can be used to track in change interference in the adaptive filtering on a certain range of frequency. Adopting neural network based nonlinear adaptive filter [10] which has a better way to eliminate the baseline drift, pseudo-differential effects. But the adaptive filter used in the template, which are subject to the impact of variation of QRS wave, while the neural network of the large amount of arithmetic operations, which has a big limitation for the clinical application of ECG analysis. The concept of Wavelet transform (Wavelet Transform) was proposed by geophysicist J. Morlet in analysis and processing geophysical data in the French in 1984, which has been widely used in biomedical, addresses exploration, satellite navigation objects recognition, computer vision and other technology field. Donoho and Johnstone proposed wavelet space adaptive noise reduction method [11], which has important theoretical and applied value, but after the wavelet de-noising of space to adapt, Gibbs oscillations often occur at the QS-wave, which result in signal distortion in strong noise background. Literature [12] proposed means of a stationary wavelet transform de-noising of ECG methods in the wavelet space to adapt in ECG denoising deficiencies, which can inhibit the Gibbs phenomenon occurs with a good method of wavelet de-noising of space to adapt and maintain well the geometric characteristics of the ECG signal.

High pass filters, median filter and wavelet transform methods can be a very good filter in the signal baseline drift. But ensuring the filtering effect at the same time, we should further consider real-time of the algorithm. Because the signal of the wavelet transform is completed usually the signal convolution and wavelet functions, the calculation volume of signal decomposition and reconstruction is large. Especially in the signal length is large, the wavelet function convolution and the associated large amount of computation addition, which is not conducive to real-time signal processing. Real-time of high-pass filter is better, but its signal processing resulting in distortion, which is determined by the high-pass filter of own characteristics. The median filter is just sequence and statistics, which has simple algorithm and relatively fast computing speed characteristics. In short, median filtering method effectively suppress baseline drift noise in the ECG signal without distortion, select the appropriate size of the median filter window, which can be possible to remove the noise of the baseline drift based on maintain the signal accuracy, and the long-time ECG single records is coped can get a better results [11].

A new method was proposed for removing power line interference in ECG signals based on EMD and adaptive filter [13]. The performance of the method was tested with actual ECG signals. EMD was developed as a non-parametric data-driven analysis tool for nonlinear and non-stationary signal processing. It exhibits an ability to analyze signal with excellent time resolution. Least mean square (LMS) algorithm developed by Window and Hoff is the most widely used adaptive filtering algorithm which is simple and powerful. Results indicate that the method is powerful and useful and the power-line interference can be eliminated from the ECG signal without affecting its spectrum [13]. A novel power-line interference (PLI) detection and suppression algorithm was proposed to pre-process real time electrocardiogram (ECG) signals based on recursive least square (RLS) adaptive notch filter instead of LMS [14]. This algorithm first compares the energy at the harmonic frequency against the energy at neighboring frequencies of the ECG power spectrum, and employs an optimal linear discriminant analysis (LDA) algorithm to determine whether PLI interference exists in the ECG signal. If the presence of PLI is detected, it then applies a recursive least square (RLS) adaptive notch filter to suppress the interference. Extensive simulation results indicate that the algorithm consistently exhibits superior performance in terms of less ECG distortion, faster convergence rate and numerical stability [14].

In the application of noise cancellation, least mean-square (LMS) algorithm is commonly used on adaptive filtering [15]. As traditional fixed step size of the standard LMS algorithm between convergence rate, time-varying systems tracking and stability imbalance for the selection of step size there is a big contradiction [16]. By improving the convergence properties of LMS algorithm, reducing the complexity, etc., made some improvements in LMS adaptive filter algorithm, typically normalized variable step size LMS algorithm is NLMS. However, a serious problem associated with both the LMS and NLMS algorithms is the choice of the step-size parameter that is a trade-off between the steady-state maladjustment and the speed of adaptation [16]. The paper [16] presents an improved LMS algorithm of variable step length based on Kwong least mean-square algorithm. The algorithm proposed is used for an adaptive noise canceller. The sinusoidal signal and audio signal with Gauss white noise were simulated in noise cancellation system on the MATLAB platform. It has fast convergence and good noise suppression ability than traditional algorithms. Finally, an adaptive noise cancellation system employed DSP chip TMS320VC5509A, audio decoder chip TLV320AIC23 and related peripheral circuit was constructed; Using CCS3.3, and through the hardware emulator download link, the new algorithm improved LMS was used [16]. The performance of the modified adaptive canceller is further improved by using error filtering and adaptation blocking [17]. The windowed adaptive canceller (WAC) proposed in this paper [17] gives the best performance while dealing with randomly varying frequency deviations. When the frequency deviation is constant, the performance of windowed adaptive canceller (WAC) is poorer, when compared to the improved adaptive canceller (IAC). However, the proposed modified windowed adaptive canceller (WMAC) performs better than the improved adaptive canceller (IAC). However, the performance of improved adaptive canceller (IAC) without adaptation blocking is very poor compared to the windowed adaptive canceller (WAC) or the modified windowed adaptive canceller (MWAC) [17].

Field programmable gate array (FPGA) is widely used in many areas such as audio and video processing systems because of its powerful parallel processing ability and high performance. Most biologic signal process system requires that the hardware has large computational ability but lower power, FPGA meets the requirements. So, it is appropriate to develop biologic signal processing system on FPGA [18]. The adaptive filters can be implemented by sequential, parallel and semi-parallel architectures. The type of architecture chosen is based on sample rate and number of coefficients [18]. The parallel architecture is well suited for a high sampling rate requirements and a small number of coefficients. However, the sequential architecture is more suited for a low sampling rate requirements and a large number of coefficients. The semi-parallel architecture is a good compromise that permits to implement filters having a large number of coefficients and requiring a high sampling rate [19]. The least mean square (LMS) is the most used algorithm to iteratively minimizing the mean square error (MSE) of the system output. In some practical applications the LMS algorithm can be implemented only with delayed coefficient adaptation [20]. The use of delayed coefficient adaptation in the LMS algorithm has enabled the design of modular systolic architectures [21]. The convergence behavior of this delayed least mean squares (DLMS) algorithm, when compared with that of the standard LMS algorithm, is degraded and worsens with the increase in the adaptation delay. Modular design systolic architecture for transversal adaptive filtering that maintains the convergence behavior of the LMS algorithm by minimizing the adaptation delay, and also supports high input sampling rates with minimal input/output latency [21].

III. DISCUSSION

Using FPGAs to design adaptive cancellers has several advantages. FPGAs allow the design time to be decreased and the canceller to be set. The cost of the FPGA is low and allows the addition of more processing of the desired signal. The design can be easily modified. The adaptive canceller’s frequency response in the interest band is flatter than the analog notch filter. The width of the attenuated band of the adaptive canceller is much smaller than that of the analog notch filter. With specifically oriented architecture, a faster processing speed can be obtained, and thus, it can process signals with a broad bandwidth. Concurrent programming algorithms allow parallel signal processing using only one FPGA with several input ECG signals without a loss of speed in the process [3].

IV. FPGA DESIGN FLOW

Figure 2 shows the FPGA design flow. The objective is to satisfy the system specifications with all the computations performed during hardware implementation. Hardware architecture design starts from behavioral idea of circuit functionality to more detailed representation. The design flow includes two processes high level architecture design and register transfer level design. The architecture design process includes division of task into subtasks as per hardware implementation, interconnection of various subtasks, hardware resources for each subtask and determine subtasks to provide parallelism and pipelining. The register transfer level design includes modeling of all subtasks using sequential and combinational circuits, HDL code, determine clock frequency, initialization of circuits and verification. Finally the back end process includes the allocation of hardware resources of FPGA, placement of subtasks and interconnection among them.

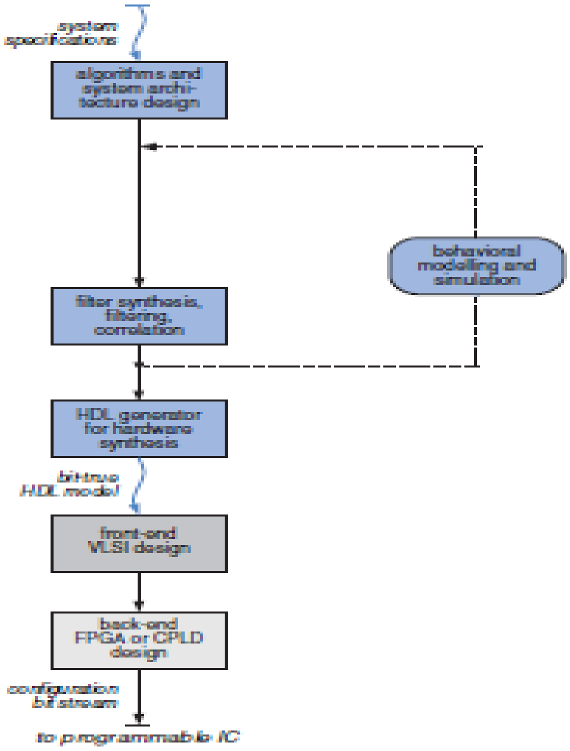

Figure 2 FPGA design flow

V. CONCLUSION

Power line interference is a challenging problem given that the frequency of the time-varying power line signal lies within the frequency range of the ECG signal. Some technical difficulties involved are low sampling frequency at which the ECG signals are obtained and the low computational resources available at the level of the apparatus. One of the possible alternatives to take frequency variations into account is the use of adaptive notch filters. Least mean-square (LMS) algorithm is commonly used on adaptive filtering. A practical difficulty in the implementation of LMS algorithms is the selection of the step-size parameter that decides the steady-state misadjustment and the speed of adaptation. The LMS algorithm can be implemented with delayed coefficient adaptation. The use of delayed coefficient adaptation in the LMS algorithm has enabled the design of modular systolic architectures. Use of systolic architectures in the implementation of LMS algorithm results in reduced area and high speed of operation. Adaptive interference cancellers are implemented using general-purpose microcontrollers or digital signal processors. These solutions are not optimum since they have low processing speed and sequential execution due to the fact that adaptive cancellers are implemented with a software program. Another solution is the implementation of the adaptive controller with field-programmable gate array (FPGA). The fundamental advantage that FPGAs offers is the parallel implementation of ECG signal processing algorithms without losing processing speed. It also provides additional control and management features in monitoring the ECG process. FPGA based design offers use of systolic architectures in the implementation of LMS algorithm.

VI. FUTURE WORK

Real time adaptive power line interference canceller with advancement in removal of noise other than PLI can be developed in future. This system will definitely help in efficient diagnosis of heart related problems.

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