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A SURVEY OF INTERFERENCE CANCELLATION IN BIOSIGNALS

[1]C.KEZI SELVA VIJILA, [2]P.KANAGASABAPATHY, [3]EBBIE SELVA KUMAR

[1]Prof., Department of ECE, Christian College of Engineering & Tech., Oddanchatram, India
[2]Professor Emiritus., Department of Instrumentation Engineering, MIT, India
3Asst. Prof., Dept. of EEE, James College of Engineering & Tech., Kanyakumari, India
E-mail: [1]vijila_2000@yahoo.com

ABSTRACT

Interference cancellation is widely used in a number of application such as acoustic and speech signal processing, data communication, biological signal acquisition etc. Many papers with different approaches have been reported to cancel interferences in biosignals. This paper provides a survey of existing methods for interference cancellation in ECG signal, FECG signal, EEG signal, and EMG signal, and also includes the survey of interference cancellation using some AI techniques. The outline of the methods used for interference cancellation is shown in Figure 2.1. Interference cancellation in biosignals can be implemented using non-adaptive and adaptive methods. Techniques based on prior knowledge of the signal and the noise characteristics such as averaging, correlation etc have been widely used for interference cancellation in biosignals. But the drawback of non-adaptive techniques is that they are time invariant in nature. This problem has been overcome by the adaptive methods, which comprise the AI techniques. This paper provides the detailed survey of interference cancellation in different biosignals.

Keywords: *Interference Cancellation, Biosignals, Survey, Artificial Intelligence, Adaptive, Non-Adaptive*

1. ADAPTIVE INTERFERENCE CANCELLATION

The non-adaptive techniques were the initially used methods for interference cancellation. One of the widely used non-adaptive interference cancellation techniques was Wiener optimal filtering. The limitations of the Wiener filter are the requirements of autocorrelation matrix Φ and cross-correlation vector θ. It is a time consuming process as it involves matrix inversion. These limitations have been rectified by using AIC.

Widrow et al (1960) have devised the Least Mean Square (LMS) adaptive algorithm and Adaline network at Stanford University which was the most widely used and the simplest one. The strength of the LMS resides basically on its inherent simplicity and ease of mathematical computation. But the practical limitations of LMS filter are effect of non-stationary interferences on the signal, effect of signal component on the interference, computer word length requirements, coefficient drift, slow convergence rate and higher steady-state error.

Koford et al (1966) have worked on adaptive systems. Huhta et al (1973) have built an Adaptive Noise Cancellation (ANC) system at Stanford University to cancel the 60 Hz interference at the output of an electrocardiographic amplifier and recorder. Widrow et al (1975) have applied ANC concept to cancel various forms of periodic interferences in electrocardiography, speech signals, and broad band interference in the sidelobes of an antenna array. Widrow et al (1976) and Glover (1977) have demonstrated the ability of ANC to reduce additive periodic or stationary random interference in periodic and random signals.

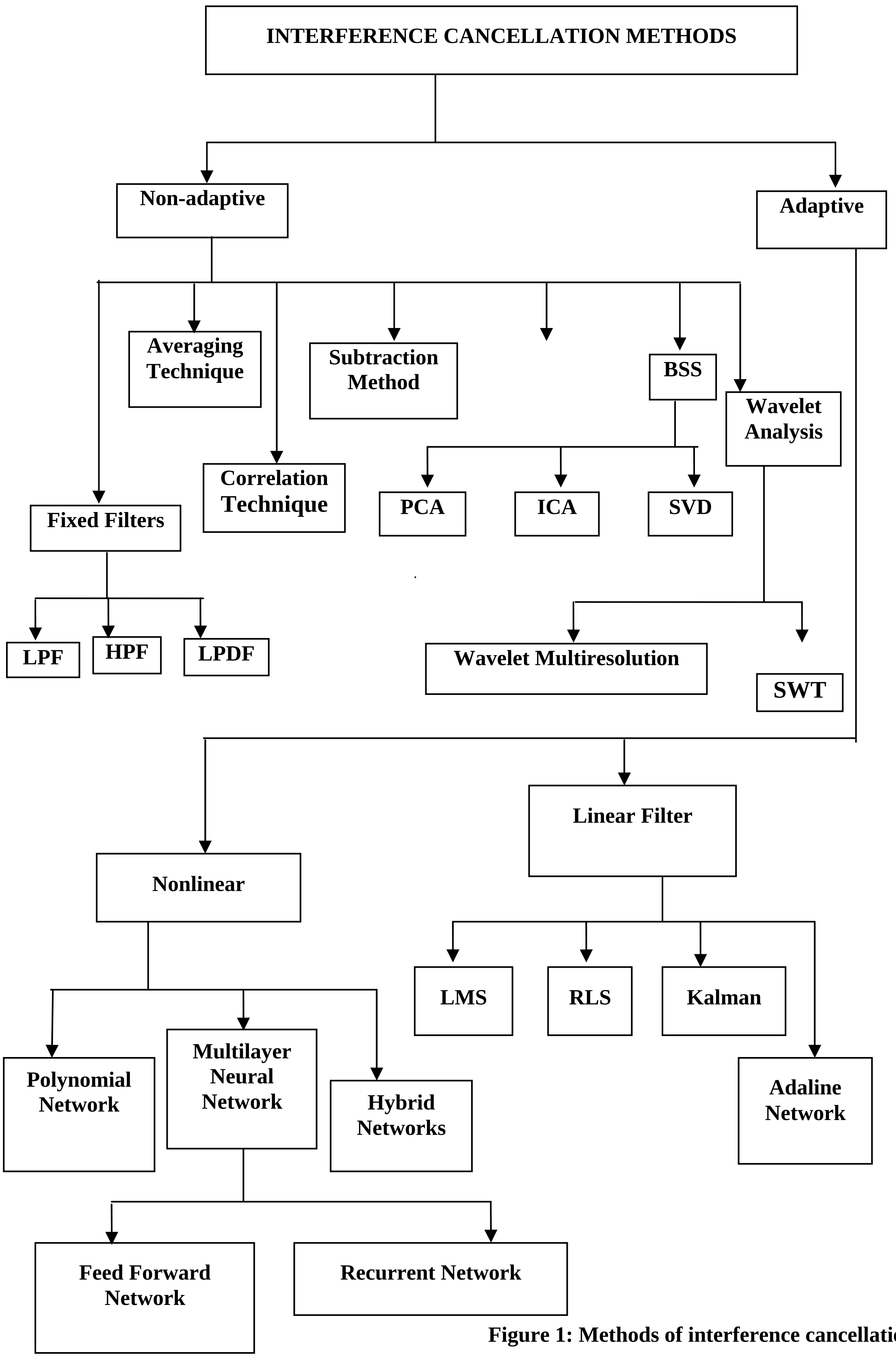

Figure 1: Methods of interference cancellation

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The Finite Impulse Response (FIR) adaptive filters developed by Widrow et al (1975, 1976) often require the use of high-order filters to achieve good performance, especially at low SNR. Widrow et al (1976) have made a comparative study of three adaptive algorithms namely differential steepest descent, LMS and the linear random search, and demonstrated the applications of these algorithms. They have reported that though FIR filter has the advantages of simplicity, and guaranteed stability, the filter performance is not optimal.

A gradient adaptive lattice noise canceller has been presented by Griffiths (1978). A general form of a noise cancellation has been reported by Benjamin (1982) using a signal modeling approach. It combines two Infinite Impulse Response (IIR) filters namely a noise canceller and a line enhancer. He has proposed an IIR filter structure and a recursive prediction error algorithm for estimating its parameters. Though this algorithm has superior convergence properties than LMS, it is sensitive to computer round off errors, computationally more complex and also structurally complicated.

Suzuki et al (1995) have developed a real-time adaptive filter for the suppression of ambient noise in lung sound measurements. Noninvasive measurements of Somatosensory Evoked Potentials (SEP) have both clinical and research applications. The electrical artifact which results from the stimulus is an interference which can distort the evoked signal, and introduce errors in response to onset timing estimation. ANC filter with a neural network as the adaptive element has been investigated by Grieve et al (2000) for the reduction of stimulus artifact in SEP measurement.

Hyung-Min Park et al (2002) have proposed ANC based on Independent Component Analysis (ICA) which utilized higher-order statistics. Experimental results show that the proposed method provides much better performances than conventional LMS approach in real world problems. Joonwan Kim et al (2003) have proposed a varying step size LMS for possible improvements in the performance of adaptive FIR filters in non-stationary environments.

2. INTERFERENCE CANCELLATION IN ECG SIGNAL

Many researchers have proposed methods for cancelling a periodic interference namely the power line interference from the ECG recordings. Widrow et al (1975) have mentioned the use of a two-weight adaptive filter. Fergjallah et al (1990) have used frequency-domain digital filtering techniques. Kumaravel et al (1998) have described a method based on genetic algorithm. Ziarani et al (2002) have presented a nonlinear adaptive method. Martens et al (2004) have used a simple ANC with internal reference signal. They have neglected the presence of power line harmonics and have not succeeded in the removal of the interference in the case of significant line frequency deviations. Martens et al (2006) have proposed an improved adaptive canceller for the reduction of the fundamental power line interference component and harmonics. The signal to power line interference ratio obtained using this method is 30 dB higher than that produced by a notch filter.

Different filter structures have been proposed by Thakor et al (1991) to eliminate the baseline wander, 60 Hz power line interference, muscle noise and motion artifact. Soo-Chang Pei (1995) has investigated a technique for suppressing the transient states of IIR notch filter. The performance of the notch filter with transient suppression is better than that of the conventional notch filter with arbitrary initial condition. Yilmaz et al (1996) have mentioned some aspects of using dynamic neural networks in predictive-type ECG filtering in comparison with adaptive linear filters. The results indicate that the use of variant step size in learning algorithms improves the signal quality

Paul et al (2000) have proposed a transform domain Singular Value Decomposition (SVD) filter for suppression of muscle noise in exercise ECG. A significant advantage of this method lies in its ability to perform noise suppression independently on a single lead ECG record with only a limited number of data samples. Nikolaev et al (2006) have proposed transform domain denoising to suppress EMG interference in ECG signal. It has limited ability to suppress low frequency noise component. Barbosa et al (2003) have proposed a technique to improve the quality of high-resolution ECG by weighting the coherent average of beats by a function of the energy of the corrupting myoelectric noise. The results obtained with 20 patients indicated that the method requires fewer beats than conventional non-weighted average method to achieve the same noise level. Ban-Hoe Kwan et al (2005) have proposed a method using

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Legendre moments to reconstruct ECG signal immersed in noise.

3. INTERFERENCE CANCELLATION IN FECG SIGNAL

Hon et al (1964) have used averaging techniques for improving the SNR for repetitive signals, such as the FECG. The major drawback in signal averaging is that it removes short term changes in the ECG waveform. Further, the presence of significant low frequency noise components reduces the effectiveness of averaging. Van Bemmel (1968) has developed a correlation technique for detecting the presence of a fetal heart signal in an abdominal signal corrupted by noise. However, correlation technique is not generally effective in the detection of non-stationary signal.

Widrow et al (1975) have used ANC to produce a clear FECG signal from four thoracic signals and one abdominal signal. The adaptation criterion is the minimization of the output signal power or Mean Square Error (MSE). The subtraction method used by Bergveld et al (1981) is the oldest and straightforward approach. It involves the direct subtraction of a near thoracic MECG from an abdominally measured composite (maternal and fetal) heart signal. The major difficulty of this technique is the fact that the measurement of the thoracic MECG will rarely match the scale of the abdominal MECG signal. Consequently, when the signals are subtracted, a pure FECG is rarely obtained.

The real time FECG monitoring system has been implemented by Park et al (1988) in which an adaptive multi-channel noise canceller was realized using the TMS32020 programmable digital signal processor. The coefficients of the multi-channel filter are updated using the LMS algorithm. Abboud et al (1989) have studied the spectral curves of the averaged fetal and maternal electrocardiograms as recorded from the abdomen. The power spectrums were obtained using a technique which includes the subtraction of an averaged MECG waveform using cross-correlation function and fast Fourier transform algorithm. This method is not effective due to poor SNR, high rate of coincidence between maternal and FECG, and the similarity in the frequency spectra of the signal and noise components.

Callaerts et al (1990) have presented and compared three methods making use of the SVD of a matrix to extract the FECG from cutaneously recorded electrode signals. The apparent lack of success of various earlier approaches like coherent averaging, matched filtering, auto and cross-correlation based methods, adaptive filtering, sequenced adaptive filters, etc., are explained in this paper. Park et al (1992) have used an efficient algorithm for detecting the presence of a fetal QRS complex. The proposed method computes the averaged magnitude of the difference between the FECG signal and the reference signal to detect the fetal QRS event.

An approach to enhance the FECG via a noninvasive procedure using Genetic Algorithm (GA) has been suggested by Horner et al (1992). It is based on subtracting a pure MECG from an abdominal signal which contains FECG and MECG. The difference between straight subtraction and the GA based method is that the subtraction via GA is a near optimal subtraction which eliminates the MECG in the abdominal signal. Outram et al (1995) have presented novel optimum curve fitting and digital filtering techniques that make it possible to enhance the quality of the FECG with minimal distortion and to measure, on a beat by beat basis, almost any feature like time constants, amplitudes, areas, maxima and minima from the FECG waveform accurately. After detecting the R-wave, an optimal approximation of the baseline shift has been obtained using a curve fitting technique and then subtracted from the raw ECG signal. After baseline removal, the SNR is improved further by averaging and digital low pass filtering to reduce the effect of muscle and random noise.

Ye Datian et al (1996) have implemented a new wavelet analysis method in the detection of FECG from abdominal signal. Tests on clinical data have shown that the proposed method can be effective in detecting the FECG signal in many cases when compared with other methods in practice. But the difficulty in the selection of threshold value and the influence of mother wavelet in the final result leads to complexity in the system design.

Echeverria et al (1996) have used a wavelet multiresolution decomposition and a pattern matching procedure. The output obtained still contains the MECG. Echeverria et al (1998) have developed a procedure called Wavelet Analysis and Pattern Matching (WA-PM), for the off-line processing of abdominal ECG. Although the WA-PM procedure is off-line and time

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consuming, the authors have concluded that it is a reliable method for the additive noise reduction and maternal QRS cancellation. Khamene et al (2000) have developed a wavelet transform-based method to extract the FECG from the composite abdominal signal. It is based on the detection of the singularities obtained from the composite abdominal signal, using the modulus maxima in the wavelet domain. Modulus maxima locations of the abdominal signal are used to discriminate between maternal and fetal ECG signals. The high performance that has been achieved is primarily due to the fact that the robust feature of the ECG signals, namely their singular points, has been exploited. Another benefit of this technique is the relaxation of the assumptions underlying alternative methods.

Mochimaru et al (2002) have used wavelet theory to detect the FECG. This method gives good time resolution and poor frequency resolution at high frequencies, and good frequency resolution and poor time resolution at low frequencies. Jafari et al (2005) have addressed the problem of FECG extraction using Blind Source Separation (BSS) in the wavelet domain. Their new approach is advantageous when the mixing environment is noisy and time-varying.

Zarzoso et al (1997) have discussed MECG and FECG separation using BSS. In this configuration, the application of ICA faced limitations due to problems inherently related to tissue conductivity, electrode efficiency, and other factors that caused the signal mixture at the sensors to be non-instantaneous. From the BSS point of view, FECG extraction has been achieved through the estimation of the independent sources of fetal cardiac bioelectric activity. The ECG source signals enable the reconstruction of the fetal heart components in the recordings, free from MECG and other disturbances. Kam et al (2000) have showed simulation studies using BSS algorithm to deal with the separation of FECG of twins. De Lathauwer et al (2000) have proposed blind source subspace separation as an interesting tool for the extraction of the ante partum FECG from multilead cutaneous potential recordings. The technique has been illustrated by means of a real-life example. Zarzoso et al (2001) made a comparative study of the BSS procedure based on higher-order statistics and Widrow's multi reference adaptive noise cancelling approach.

Ananthanag et al (2003) have made an analysis and study of some major algorithms like Bell and Sejnowski's infomax algorithm, Cardoso's joint approximate diagonalization of eigen matrices algorithm, Hyvdrinen's fixed-point algorithm and Comon's algorithm for FECG extraction. Different amplitude ratios of the simulated maternal and FECG and different values of additive white Gaussian noise have been investigated for robustness. It has been observed that if the ratio of the amplitude of maternal to FECG is 10:1 with an input SNR of 2 dB, all four algorithms are able to extract the FECG. Salustri et al (2005) have applied ICA to the magneto cardiographic data of fetal. In particular, an extension of the cumulant-based iterative inversion algorithm has been proposed to include a two-step signal subspace subdivision, which allows the user to control the number of components to be estimated by analyzing the eigenvalues distribution in an interactive way.

Longini et al (1997) have discussed the orthogonal basis method for FECG extraction. The advantages claimed by this method include, ease of use in clinical settings, real time implementation and most importantly good results. Kanjilal et al (1997) have used SVD to identify the MECG and the FECG components in terms of the Singular Value (SV) decomposed modes of the appropriately configured data matrices. Selective separation of the SV-decomposed components has been used for the elimination of the MECG and determination of FECG. The unique feature of the method is that one composite maternal ECG signal is required to determine the FECG component. The method is numerically robust and computationally efficient.

De Lathauwer et al (2000) have discussed the concept, pros and cons of techniques relying on the ordinary SVD, quotient SVD and multilinear SVD for the extraction of the FECG from multilead cutaneous potential recordings. The multilinear SVD approach has the advantage that the mixing matrix can be estimated in an unsupervised way. In addition, the separation of the measurements into statistically independent source signals is easier to interpret than decomposition in time-orthogonal principal components. On the other hand, the algorithm is computationally more complex. These methods are briefly compared in terms of computational complexity, robustness, required interaction with the user and the amount of information provided. Ping Gao et al (2003) have used combined SVD and ICA for the fetal heartbeats detection. The

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SVD contributed to the separability of each component and the ICA contributed to the independence of the two components. The experimental studies showed that the proposed method is more accurate than using SVD only.

Azad et al (1998) have described an improved scheme for detecting the presence of the QRS complexes from the enhanced FECG signal obtained by using a fuzzy decision algorithm. The decision method identifies maternal and FECG from maternal abdominal recordings. This work is a post-processing technique for detecting the QRS complexes from abdominal recordings. Reliable detection has been achieved except at very noisy instances. A nonlinear state space projection technique which was originally developed for noise reduction in deterministically chaotic signals has been used by Richter et al (1998) to suppress maternal and noise contaminations in single lead FECG recordings. The method has been successfully applied to recordings with fetal components and noise of comparable amplitude.

Kuei-Chiang Lai et al (2002) have presented a two-stage successive cancellation algorithm that sequentially separates fetal and maternal heartbeats from an intrauterine ECG signal containing both fetal and maternal QRS complexes. The ECG signal has been modeled as a series of fetal, maternal, and noise events. Peak detection is first employed to locate the potential fetal and maternal QRS complexes, referred as candidate events. Each stage automatically generates a template of a source from the candidate events in the initialization period, and thereafter performs classification of the remaining candidate events based on a template matching technique. The detected events of the stronger signal are subtracted from the composite ECG signal prior to initialization and classification of the weaker signal. After the fetal and maternal complexes are successfully detected and separated, a counting mechanism is utilized to derive the corresponding heart rates.

Mamun Bin Ibne Reaz et al (2004) have described an adaptive method to separate FECG from composite ECG that consists of both maternal and FECG by using Adaline network. A Graphic User Interface program has been written in Matlab to detect the changes in extracted FECG by different values of momentum, learning rate and initial weights used in the network. It is found that filtering performs best by high learning rate, low momentum, and small initial weights.

Khaled Assaleh et al (2005) have proposed polynomial networks technique to nonlinearly map the thoracic ECG signal to the abdominal ECG signal. The FECG is then extracted by subtracting the mapped thoracic ECG from the abdominal ECG signal. Visual test results obtained from real ECG signals show that the proposed algorithm was capable of reliably extracting the FECG from two leads only.

4. INTERFERENCE CANCELLATION IN EEG SIGNAL

A common method of artifact removal is the visual inspection of the signals by experts. The data whose amplitude exceeds a predefined threshold has been discarded in threshold method. This is based on the fact that most of the artifacts have considerably larger amplitude than the EEG signals. The one implication of threshold method is the potential loss of valuable EEG activity, which has been masked by the large amplitude artifacts. Also, recording of EEG data is a time-consuming process, spanning over a number of different sessions. Thus, all recorded data is valuable and discarding a portion of it is not a very favorable option.

Barlow et al (1981) have removed an eye movement artifact called Electrooculogram (EOG) from the EEG recordings using subtraction method. An Auto Regressive Moving Average with Exogenous (ARMAX) model has been used by Haas et al (2003) to model the recordings as a linear combination of background EEG activity and EOG. The background EEG is then obtained via estimation of the corresponding ARMAX parameters. Even though this method is able to separate some EOG artifacts that are not removable using standard linear regression techniques, it has been achieved at the expense of increased computational complexity and the risk of introducing new EOG artifacts, if the underlying EEG is not modeled properly.

Woestenburg et al (1983) have presented a regression technique that is based on the assumption that a clean measured EOG can be subtracted from the recordings. However, Croft et al (2000) have discussed EOG correction and concluded that the EOG is also contaminated to a degree with EEG signals. Thus, regression of the EOG also results in the removal of some EEG activity. Gralton et al (1983) have described a new off-line procedure called Eye Movement Correction Procedure (EMCP) for dealing with

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ocular artifacts in event related potential recordings. The major advantage of this procedure is that it permits retention of all trials irrespective of ocular artifact. Furthermore, there is no need for subjects to restrict eye movement. In comparison to the procedures suggested by others, EMCP also has the advantage that separate correction factors are computed and applied for blinks and other movements.

Ifeachor et al (1986) have built and successfully tested an automatic online microcomputer-based ocular artifact remover using Recursive Least Square (RLS) algorithm. Kenemans et al (1991) have applied three different correction methods namely a simple regression analysis in the time domain, a multiple-lag regression analysis in the time domain, and a regression analysis in the frequency domain for interference cancellation. Rahalova et al (2001) have presented a new approach for detection of artifacts in EEG recorded during sleep.

Berg et al (1994) have reported that Principal Component Analysis (PCA) outperforms the regression based methods. However, PCA method also requires an accurate modeling of propagation paths for the signals involved. PCA method cannot completely separate ocular artifact from EEG, when both the waveforms have similar voltage magnitudes. Hence Lagerlund et al (1997) have used PCA with SVD. It also requires the distribution of the signal sources to be orthogonal and its effectiveness is limited to decorrelating signals and thus it cannot deal with higher-order statistical dependencies.

Comon (1994) has introduced ICA which is an extension of PCA. It not only decorrelates but can also deal with higher order statistical dependencies. Vigário (1997) has used ICA for separating EOG from EEG. Most popular ICA algorithms that have been used by numerous researchers for denoising EEG are Infomax, Extended Infomax (Lee et al 1996) and Joint Approximation Diagonalisation of Eigen Matrices (JADE) (Cardoso 1998). ICA algorithms are superior to PCA in removing a wide variety of artifacts from the EEG, even in the case of comparable amplitudes. However, ICA algorithms are not automated, and require visual inspection of the independent components to decide their removal.

Vigon et al (2000) have made quantitative evaluation of different techniques used for noise cancellation in EEG. It has been demonstrated that the signal separation techniques of JADE and extended ICA are more effective than EOG subtraction and PCA for removing ocular artifact from the EEG. The successful application of ICA for artifact removal from the EEG has been reported by Jung et al (2000), where a number of different artifacts have been isolated and successfully removed from EEG and magnetoencephalogram recordings. The drawbacks of this method are firstly, visual inspection of the obtained sources is still needed in order to perform artifact rejection and secondly, there is unwanted data loss in the cases where the entire trials are rejected. Nicolaou et al (2004) have discussed the application of a specific extension of ICA called Temporal Decorrelation Source Separation (TDSEP) for the problem of automatic artifact removal from EEG signals. One of the advantages of TDSEP is that, because separation is based on the correlation of the sources, TDSEP can separate signals whose amplitude distribution is Gaussian.

Selvan et al (1999) have described two popular adaptive filtering techniques, namely adaptive noise cancellation and adaptive signal enhancement using single recurrent neural network for the removal of ocular artifacts from EEG. Robert et al (2002) have presented a spectrum of neural network applications in EEG processing. Shusaku Shigemura et al (2004) have used a neural network with non-recursive second order volterra filters to eliminate the artifacts from EEG signals.

Browne et al (2002) have used statistical wavelet threshold as a means of distinguishing the EEG and the artifact signals. It is only capable of separating artifacts that are well localized in the time-frequency domain or that have a spectrum which is uncharacteristic of the EEG. These results are better when compared to expert artifact rejection in some cases, but they fail to improve the removal of baseline drift, eye movement and step artifact. Tatzana Zikov et al (2002) have proposed a wavelet based denoising technique for removal of ocular artifacts in EEG. This method relies upon neither the reference EOG nor visual inspection. However, the threshold limit is estimated from the uncontaminated baseline EEG, which is recorded from the same patient.

Hae-Jeong Park et al (2002) have used two-step process i.e. ECG artifact detection using the energy interval histogram method and ECG artifact elimination using a modification of ensemble average subtraction. This method has

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already been proposed to estimate the rate of false positives and false negatives that are necessary to determine the optimal threshold for the detection of the ECG artifact.

He et al (2004) have described a method for removing ocular artifacts based on adaptive filtering. The method uses separately recorded vertical EOG and horizontal EOG signals as two reference inputs and then subtracted from the original EEG. The method was implemented by an RLS algorithm to track the non-stationary portion of the EOG signals. It is easy to implement, stable, converges fast and is suitable for on-line removal of EOG artifacts. Min Shao et al (2004) have used interference cancellation algorithm to extract the fetal EEG signal.

5. INTERFERENCE CANCELLATION IN EMG SIGNAL

Usui et al (1982) have defined the Low Pass Differential Filter (LPDF) for the analysis of EMG signals. It is not an ideal Low Pass Filter (LPF); there exists severe Gibbs phenomenon, that is, the leakage of energy frequency out of the filter pass-band. As a result, many high frequency noise components will pass through the filter. An alternative to this method is the weighted low-pass differential filter which is proposed by Xu et al (2000). The main difference between these filters is that the latter includes an appropriately weighted window to reduce the Gibbs effect.

Levineet et al (1986) have described a cross-correlation procedure for removing contaminated ECG complexes from the Diaphragmatic Electromyogram (EMGdi). First, the operator selects ECG templates from the EMGdi signal during expiratory intervals. Then these templates are used to locate ECG complexes occurring during inspiratory EMGdi activity. Next, at the point of maximum correlation between the template and these ECG complexes, the template is adjusted in size and offset to “match” the ECG complex. Finally, the modified template is subtracted from the EMGdi signal. The power spectral density obtained from processing EMGdi signals by this method is compared with that obtained from the EMGdi signal in which ECG complexes had been removed by gating. The power spectral density obtained from the above two methods indicates no significant differences with respect to the following features: centroid frequency, median frequency, total power, standard deviation, skewness, and kurtosis. Blanking based techniques have been described by Knaflitz et al (1988). This method either removes some signal components or leaves a part of the artifact.

Akkiraju et al (1992) have implemented the ANC technique to reduce the interfering cardiac activity from the recorded myoelectric activity. The adaptive noise canceller implemented in a transversal structure was found to successfully reduce the corrupting cardiac activity. Chen et al (1994) have also used adaptive cancellation of ECG artifacts in the EMGdi signals. Marque et al (2005) have proposed an adaptive filtering algorithm specifically developed for the rejection of the ECG corrupting Surface Electromyogram (SEMG). The first step of the study is to choose the ECG electrode position in order to record the ECG with a shape similar to that found in the noisy SEMGs. Then, the efficiency of different algorithms is tested on 28 erector spinae SEMG recordings. More precisely, the best results have been obtained with the simplified formulation of a fast RLS algorithm.

Redfern et al (1993) have used high pass filter (HPF) to effectively remove ECG artifact from raw EMG recordings from the rectus abdominis, external oblique and erector spinae muscles. A HPF with corner frequency around 25 Hz has been found to be best to remove ECG artifact with minimal impact on the total power of the EMG. Baratta et al (1998) have suggested a simple method for removing power line artifact from EMG in the time domain. The amplitude and phase of the fundamental frequency of the power line interference are estimated from a quiet segment of the EMG recording. A sinusoidal waveform with the same amplitude and phase as the interfering signal is then subtracted from the entire EMG record. This method assumes that the amplitude and phase of the power line interference do not change during the EMG recording session, which is true only under restricted experimental conditions.

Sinderby et al (1995) have described a set of computer algorithms that automatically select EMGdi free of the ECG and numerically quantify the common artifacts that affect the EMGdi. The frequency domain application of computer algorithms offers a reliable and reproducible means to objectively quantify the sources that contaminate the EMG. Conforto et al (1999) have compared the following four techniques for motion artifact removal from EMG: 1) filtering with an eighth order

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Chebyshev HPF with corner frequency at 20 Hz; 2) filtering with a moving average filter to estimate the motion artifact and subtracting the estimated artifact from the signal record; 3) filtering with a moving median filter to estimate the motion artifact and subtracting the estimated artifact from the signal record; and 4) filtering using an adaptive filter based on orthogonal Meyer wavelets. These techniques have been tested on simulated bursts of EMG contaminated with low frequency artifact and on real dynamic gait EMG contaminated with motion artifact. The wavelet filter is found to give superior performance in information preservation and time-detection of EMG bursts. Grujic et al (2004) have made a comparison of wavelet and classical digital filtering procedures for denoising of SEMG signals. The main advantages of wavelet technique are that no artificial information is introduced into the filtered signal and that the signal components may be independently thresholded in order to generate the filtered signal. This allows for some flexibility that may be required in different applications. The main drawback of this method is that a mother wavelet has to be defined apriori and this choice may influence the final results. Azzerboni et al (2004) have presented a method based on the combined use of wavelet transform and ICA. In this preliminary study, an user interface is needed to identify the artifact.

Huang et al (1998) have described a new technique for analyzing nonlinear and non-stationary data. This technique uses the empirical mode decomposition, in which any complicated data set can be adaptively decomposed into a finite, and often small, number of intrinsic mode functions. The results and ideas presented in this study are useful for any application that requires the filtering of EMG signals in the pre-processing stage. Adriano et al (2006) have used the same procedure for filtering EMG signals and the results obtained from the analysis of synthetic and experimental EMG signals showed that this method can be successfully and easily applied in practice for attenuation of background activity in EMG signals.

Yuancheng Deng et al (2000) have addressed an event-synchronous interference canceller for cancellation of ECG interference in EMGdi signals. It has been evaluated using both computer simulations and real EMGdi data, and its efficiency in interference cancellation has been compared to that of event-synchronous adaptive interference canceller. The computational load of event-synchronous interference canceller is much lesser than that for event-synchronous adaptive interference canceller. Mandrile et al (2003) have investigated the amplitude properties of the artifact generated on the recorded SEMG signals during transcutaneous electrical muscle stimulation.

The detection of anticipatory postural adjustment via trunk muscle onsets from EMG signals can be problematic due to baseline noise or ECG artifact. Allison (2003) has presented two detection methods
to determine the onsets of trunk muscles. In spite of the robustness of the algorithm, the findings suggest that statistical assessments should be used to target trials for selective visual inspection for subtle trunk muscle onsets. Ping Zhou et al (2005) have investigated elimination of ECG artifacts from the myoelectric prosthesis control signals, taken from the reinnervated pectoralis muscles of a patient with bilateral amputations at shoulder disarticulation level. The performances of various ECG artifact removal methods including HPF, spike clipping, template subtracting, wavelet threshold and adaptive filtering are presented.

Yong Hu et al (2005) have discussed a denoising method using ICA and a HPF to effectively suppress the interference of ECG in SEMG recorded from trunk muscles. The performance of this technique has been evaluated with simulation experiments. The correlation coefficients in both time-domain waveform and frequency spectrum are computed to compare the outcome of the ICA and filtering technique to the original SEMG signal. In addition, different filter bands are evaluated. The ICA based ECG cancellation using HPF with a corner frequency of 30 Hz has yielded higher mean correlation coefficients in the time domain (0.97±0.08) and in the frequency spectrum (0.99±0.06) than any other techniques.

Seedahmed et al (2006) have used the instantaneous frequency estimation method which provides the frequency components of the ECG signal as well as their time of occurrence. This helps in the removal of these artifacts from the SEMG. Simulation results have shown that Hyperbolic T-distribution has a better performance in terms of resolution, and cross terms reduction as compared to other time frequency distributions.

Ping Zhou et al (2007) have investigated the removal of ECG artifacts in real time for

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myoelectric prosthesis control, a clinical application that demands speed and efficiency. Three methods with simple and fast implementation have been investigated. Removal of ECG artifacts by digital HPF has been implemented. The effects of the variation in cutoff frequency and filter order of HPF on the resulting EMG signal are quantified. An alternative adaptive spike-clipping approach has also been developed to dynamically detect and suppress the ECG artifacts in the signal. Finally, the two methods are combined. Experimental SEMG recordings with different ECG/EMG ratios have been used as testing signals to evaluate the proposed methods.

6. INTERFERENCE CANCELLATION USING ARTIFICIALNEURAL NETWORKS

The applications of neural networks have grown dramatically in the recent years. Widrow et al (1960) have suggested the Adaline network to represent a self learning system that can adapt itself to achieve a given modeling task. The practical applications of the adaptive linear combiner in signal processing and pattern recognition have been described by Widrow et al (1988). Widrow (1975) has used Adaline and Madaline for ANC. However, the Adaline and Madaline systems had only one layer with adjustable weights, just like single layer perceptrons. Widrow (1985) has explained Adaline, Madaline, and LMS methods for ANC. Back propagation is a supervised learning technique used for training Artificial Neural Network(ANN).

Ng et al (2002) used BPN to diagnose breast cancer. An ANC filter which uses a neural network as the adaptive element has been investigated by Grieve et al (2000) to filter the stimulus artifact from somato sensory evoked potentials. A neural network filter with a modified back propagation algorithm for higher order statistics has been proposed by Bor-Shyh Lin et al (2005) to suppress the additive Gaussian noise and to improve the performance of evoked potentials estimation. The major limitations of the BPN are the slow rate of convergence, and rigidity of the network architecture. Cascade Correlation Network developed by Fahlaman et al (1990) have addressed both these issues bydynamically adding hidden units to the architecture.

Modified cascade-correlation learning architecture has been developed by Karunanithi et al (1993) for radar signal pulse detection. Comparisons with networks trained using back propagation and GA have indicated that the CCN trains approximately 50 times faster and produces much better generalization. Phatak et al (1994) have modified the algorithm to generate networks with restricted fan-in and small depth (propagation delay) by controlling the connectivity. The results reveal that there is a tradeoff between connectivity and other performance attributes like depth, total number of independent parameters, and learning time. Adams et al (1995) have designed the CCN for classification tasks and have tried to modify CCN to perform function evaluation and interpolation tasks.

Jenq-Neng et al (1996) have provided an analysis to show that the maximum correlation training criterion used in cascade-correlation learning tends to produce hidden units that saturate and thus makes it more suitable for classification tasks instead of regression tasks. An experimental evaluation of the CCN has been carried out by Ribeiro et al (1997) in different benchmarking pattern recognition problems. An extensive experimental framework has been developed to establish a comparison between the CCN and the more traditional Multi Layer Perceptron (MLP) and Radial Basis Function (RBF). In addition to some clear potential advantages observed in the CCN such as the on-learning definition of the number of hidden units, the practical satisfactory results obtained suggest that the CCN model may represent in some situations an alternative to other traditional models such as the MLP and RBF networks.

The major drawback of CCN is that the error surface is zigzag and not smooth due to the use of maximum correlation criterion that consistently pushes the hidden neurons to their saturated extreme values instead of active region. To alleviate this drawback of the original CCN two new cascade-correlation learning networks have been proposed by Ivan Petrovic et al (1998). New approach for weight initialization in cascade-correlation learning proposed by Lehtokangas (1999) is based on the concept of stepwise regression. Empirical simulations show that the new method can significantly speed-up cascade-correlation learning. Some applications of the CCN are given by Nikola Masic et al (1996), and Anna Maria Bianucci et al (2000).

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7. INTERFERENCE CANCELLATION USING ANFIS

The architecture and learning procedure underlying Adaptive Neuro Fuzzy Inference System (ANFIS) has been reported by Jang (1993), which is a Fuzzy Inference System (FIS) implemented in the framework of adaptive networks. The practical guidance about ANFIS with examples has been explained by Jang et al (1995). Also, Jang et al (1997) have provided the theory behind ANFIS.

Hee-Kyoung Park et al (1999) have presented a neuro-fuzzy controller for the adaptive cancellation of noise in a duct. An ANC system generates controlled sound pressure with the same amplitude and with opposite phase as that of the noise to be eliminated. Simulation results have shown that the proposed ANC system successfully cancels the noise. Anna Esposito et al (2001) have used ANFIS for identifying a nonlinear model of the unknown dynamic characteristics of the noise transmission paths. The output of this model is used to subtract the noisy components from the received signal. Once trained for few epochs with a long sentence corrupted with babble noise, the FIS obtained, has the ability to clean speech sentences corrupted by babble and also by car, traffic, and white noise, in a computational time almost close to real time.

Yin H et al (2004) have presented an application of ANC with ANN based FIS for rapid estimation of visual evoked potentials. A series of computer experiments conducted on simulated and real-test responses have confirmed the superiority of the method reported in this paper. ANFIS based
impulsive noise removal filter has been proposed by Erkan Besdok (2004) to get high performance at the restoration of images distorted by impulsive noise. It comprises three main steps: finding the pixels that are suspected to be corrupted, Delaunay triangulation and finally, making estimation for intensity values of corrupted pixels within each of the Delaunay triangles.

A new approach based on ANFIS has been presented by Inan Güler et al (2004) for the detection of electrocardiograph changes in patients with partial epilepsy. Decision making is performed in two stages i.e. feature extraction using the wavelet transforms and the ANFIS. The results obtained have confirmed that the proposed ANFIS classifier has potential in detecting the electrocardiograph changes in patients with partial epilepsy. Qin et al (2005) have used ANFIS for nonlinear noise cancellation of images. The quality in terms of MSE of image restoration using ANFIS is over 65 times better for Gaussian noise and 500 times better for salt and pepper noise than the quality obtained using conventional filtering systems.

The image restoration contaminated with Gaussian noise has been investigated in nonlinear passage with second order dynamics by Hao Qin et al (2007). Eight types of membership functions (MF) like bell MF, triangle MF, Gaussian MF, two sided Gaussian MF, pi-shaped MF, product of two sigmoid MFs, difference of two sigmoid MFs, and trapezoidal MF have been investigated. In addition, the other parameters, such as the training epochs, the number of MFs for each input, the optimization method, the type of output MFs and the over-fitting problem, are investigated. For comparison with the noise cancellation using ANFIS, 22 conventional filtering techniques such as spatial filters, optimal Wiener filter, frequency domain filters, wavelet packet, etc are simulated. The quality in terms of MSE of image restoration using the proposed noise cancellation using ANFIS (Pi-shaped MF) is at least 75 times better for Gaussian noise than that derived using any of these conventional filtering techniques.

The other applications of ANFIS have been reported by Ikonen et al (1996), Manish Kakar et al (2005), Abdulhamit et al (2007).

8. CONCLUSION

This paper has elaborately portrayed the various techniques used for interference cancellation in biosignals. The merits and demerits of the various techniques are analyzed in detail for possible usage for the future researchers. Several other novel ideas can be also derived from these works illustrated in this survey.

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AUTHOR PROFILES:

Dr. C. Kezi Selva Vijila got her B.E. degree in ECE and M.E. in Applied Electronics from Karunya Institue of Technology and Sceinces, then affiliated to Bharathiyar university, Coimbatore, India. She has 16 years of teaching experience and has published a number of papers in National and International journals. Her areas of interest are Adaptive signal processing, Image processing, Soft computing and Computer Communication. Currently, she is the Principal of Christian College of Engineering and Technology at Oddanchatram in Dindigul District, Tamilnadu. She is also the recipient of The Young Women Scientist Award given by the Government of Tamilnadu.

Dr. P. Kanagasabapathy is a Professor Emeritus in the Department of Instrumentation Engineering, Madras Institute of Technology Campus, Anna University. He received his BE (Electrical) from Thayagaraja College of Engineering, Madurai, India and his MTech (Measurement and Instrumentation) and PhD, from Indian Institute of Technology, Chennai, India. His areas of interest are process control, modeling, fault identification and control and, measurement and sensor development. He has published many papers in international journals and conferences.

Mr. C. Ebbie Selva Kumar was born in the year 1980 and he received the B.E. degree in EEE from Bangalore University Karnataka, India, in the year 2003 and M.Tech degree in Power Electronics & Drives from the SRM University, Chennai, India, in the year 2006.He has got a teaching experience of nearly 6 years. Currently, he is working as Asst. Professor/HoD in James College of Engineering and Technology, Kanyakumari District, India in the Dept. of Electrical and Electronics Engineering & simultaneously Pursuing Ph.D (Research Scholar) in Electrical & Electronics Engineering, Karunya University, Coimbatore, India. His areas of interest are Neural Networks, Fuzzy Logic, Power Electronics & Drives, Renewable Energy Sources, MATLAB,etc.