Swarm and Evolutionary Computation 14 (2014) 76–91

Contents lists available at ScienceDirect

Swarm and Evolutionary Computation

journal homepage: www.elsevier.com/locate/swevo

Regular Paper

Adaptive filtering of EEG/ERP through noise cancellers using an improved PSO algorithm

Mitul Kumar Ahirwal [a], Anil Kumar [a,*], Girish Kumar Singh [b,c]

[a] PDPM Indian Institute of Information Technology, Design and Manufacturing, Jabalpur 482011, MP, India
[b] Department of Electrical Engineering, Indian Institute of Technology, Roorkee, Uttrakhand 247667, India
[c] Department of Electrical Engineering, University of Malaya, Kuala Lumpur, Malaysia

ARTICLE INFO

Article history:
Received 21 June 2012
Received in revised form
1 October 2013
Accepted 3 October 2013
Available online 11 October 2013

Keywords:
Adaptive Filters
EEG/ERP
Detection
LMS
NLMS
RLS

ABSTRACT

In this paper, event related potential (ERP) generated due to hand movement is detected through the adaptive noise canceller (ANC) from the electroencephalogram (EEG) signals. ANCs are implemented with least mean square (LMS), normalized least mean square (NLMS), recursive least square (RLS) and evolutionary algorithms like particle swarm optimization (PSO), bacteria foraging optimization (BFO) techniques, genetic algorithm (GA) and artificial bee colony (ABC) optimization technique. Performance of this algorithm is evaluated in terms of signal to noise ratio (SNR) in dB, correlation between resultant and template ERP, and mean value. Testing of their noise attenuation capability is done on EEG contaminated with white noise at different SNR levels. A comparative study of the performance of conventional gradient based methods like LMS, NLMS and RLS, and swarm intelligence based PSO, BFO, GA and ABC techniques is made which reveals that PSO technique gives better performance in average cases of noisy environment with minimum computational complexity.

1. Introduction

Recordable brain wave in form of electrical signals replicates the response of stimulation, known as evoked potential (EPs), or event-related potentials (ERPs). Stimulation for ERP generation has various types like visual, auditory, and motor movement, etc [1–3]. Since ERPs are weak signals and buried in signals of spontaneous EEG with very low signal-to-noise ratio (SNR) [1]. Typically, EEG responses are categorized in to two types, based on the way they respond to stimulation. First type represents the time-locked and phase-locked responses, also termed as event-related potentials (ERP), and they appear for short time interval. Second type is time-locked, but not phase-locked (induced) modulation, called event-related de-synchronization (ERDS), and these are measured as alterations in the functional connectivity within the specified cortex of brain. Different analytical methods have been used for analysis of these two types of EEG changes [4].

Evoked activities responses in EEG are enhanced and extracted by simple linear methods based on synchronized averaging, while induced activities are analyzed using nonlinear methods such as power spectral analysis and rectified averaging [4]. Today, ERP analysis has become a major part of brain research. These ERP play an important role in design and development of brain computer interface (BCI) [4–6]. Effectiveness of ERP analysis depends only on EEG signal of high SNR value. However, EEG signals are noisy and non-stationary due to its process of generation from group of neurons. EEG signals are contaminated by artifacts due to line noise, muscle movements, sometime with cardiac signals (ECG), eye blinking and eyeball movements also [1,7]. Therefore, during the past decades, several techniques have been developed for the artifact removal from EEG signals [1].

Now a day's application based EEG researches are the motivation behind the need of estimation of perfect ERP signals. Point of interest (POI) based image retrieval system is implemented using rapid image triage (RIT), which is the latest example for utilization of ERP generated in response of different images. Performance of RIT system is also related with the SNR of recorded ERP which leads to need of de-noising method to improve ERP [8]. Filtering is always beneficial when it is performed before any processing on ERP. In [9], optimal filtering (OF) is designed with ICA which improves the overall results as well as helps in dimension reduction of EEG data. Variability and changes in ERP is some time necessary, but it is difficult to trace. In order to overcome these problem, a Bayesian method having two stages is proposed and tested on variability of P300 (type of visual ERP) [10]. Sources localization of ERP is also important as SNR improvement, because the number of channels reduces only when the location of generation of particular type of ERP is known, in case of multiple channels. Source localization with spatial notch filter is proposed

* Corresponding author. Tel.: +91 942 580 5412.
E-mail addresses: ahirwalmitul@gmail.com (M.K. Ahirwal), anilkdee@gmail.com (A. Kumar), gksngfee@gmail.com (G.K. Singh).

2210-6502/$ - see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.swevo.2013.10.001

in [11] which are able to localize source accurately within high noise environment. Particle filtering (PF) has been proposed in [12] in order to track the variations of P3a and P3b parameters of P300 ERP within consecutive time-locked trials of the stimulated EEGs. Since the aim is to track latency, amplitude, and width of the ERP subcomponents across the trials. Especially for mental fatigue analysis and delectation of fatigue levels where the relative variability of P300 subcomponents is the key factor, a novel spatiotemporal filtering method for single trial estimation of event-related potential (ERP) subcomponents is proposed [13]. This method is able to estimate temporally the correlated ERP subcomponents such as P3a and P3b.

The simplest and the most widely applied method for the analysis of ERPs is averaging of the measurements over an ensemble of trials, also known as ensemble averaging (EA). It is the optimal way to improve signal-to-noise ratio (SNR), when the underlying model of the observations is assumed that the ERP is a deterministic signal independent of additive background noise. ERP signals and background EEG noise are assumed to be uncorrelated in this traditional technique of EA. Based on the theory of researches present which confers the reliability of EA, probably ERP component variability is related to the psycho-physiological factors of a particular human being. Thus, in early stage of the research, many researchers have focused on the ensemble reduction in extracting a template ERP, assuming that the stimulus-induced changes in the EEG signal are very small [14–15]. Major drawback of the averaging technique is its dependency on number of trials or more trials are needed for better results. Independent component analysis (ICA) has been also employed for the purpose of noise reduction and extraction of ERPs with assumption that EEG observations are generated by linear mixing of a number of source signals, which must be statistically independent, and this is mostly true with regard to brain and ocular components [16–19].

Several wavelet based algorithms [2,20–22] have been developed and employed for noise reduction and extraction of ERPs by decomposing signals into several levels. Generally, these algorithms are called Wavelet de-noising. These techniques are complex, and are having complicated nature. Filtering is also the most commonly used method for single trial analysis of ERP, with which the contamination due to on-going background activity can be attenuated from the evoked potential. A major difficulty in the filtering method is that it offers often very low SNR or performance of the filter in the detection of the signals depends on statistical properties of the signal which is to be processed. To overcome these problems, the concept of adaptive filters and its applications as noise canceller was introduced by Widrow et al. [23]. Since then, adaptive noise cancellation techniques have been used in many engineering applications [1,23].

Literature review explores that various types of algorithms or error estimation methods have been exploited in adaptive filters to adjust the weights of filter, and error estimation according to the EEG signals and noise property [1,24–28]. Most efficient gradient based algorithms are least mean square (LMS), recursive least square (RLS) and their different variants. Recently, evolutionary techniques have emerged as robust tool for solving linear and non-linear equations. These techniques use the concept of random population generation which acts as possible solutions. Among evolutionary techniques, the most famous and robust technique are particle swarm optimization (PSO), genetic algorithm (GA), artificial bee colony (ABC), and bacteria foraging optimization (BFO). There are very few references available in which PSO, BFO and ABC have been employed for adaptive noise cancellations, system identification and channel equalization, respectively [29–37]. Genetic algorithm is the earliest optimization algorithm and also the simplest to understand. GA with its basic and modified version has been applied to optimize solution of different problems [38–40].

In this paper, a PSO and other evolutionary techniques has been assimilated with adaptive filter to de-noise the ERP. Analysis of PSO with respect to growing range of particles can be correlated with increasing noise level which is only possible with the basic and most known PSO version. Reason and motivation behind the choice of PSO for this problem are given below, as theoretically compared to other computational intelligence techniques:

I. EEG signal by nature of generation is considered as non-linear function. Hence, to perform the same type of treatment, PSO algorithm having same non-linear and stochastic nature is applied for noise cancellation. Basically, adaptive filtering for linear modeling implemented by gradient based algorithm (conventional adaptive filtering) and for non-linear modeling, adaptive Volterra filters (kind of polynomial extension to the linear adaptive filter) or non-classical adaptive filters that do not rely on linear modeling techniques that are based on evolutionary algorithm (PSO) are the best option due to its simplicity and lack of applied research in the field of EEG processing.
II. Literature review on Neuro fuzzy systems reflects that they are more oriented towards the classification application to mimic nature of human decision making.
III. Ant colony optimization is also a well known optimization method but it is more difficult to theoretically analyze the concept of pheromone accumulation with respect to filtering problem.

A detailed review on behind the choice of PSO for this problem is given in these references and the references therein [41–42].

Compared to genetic algorithm (GA), the advantages of PSO are that it is easy to implement, and there are few parameters to adjust. GA has no guidance or directional concept (Gbest) like PSO, it only depends on crossover and mutation operation which simply define statically and only provide random change in solution. PSO has been successfully applied in many areas: function optimization, artificial neural network training, fuzzy system control, and other areas, where GA can be applied. Advantages of PSO over GA and simulated annealing (SA) are given in [29,41,43]. The detailed discussion is provided in [29,41,43] and the references therein. Advanced aspects of swarm intelligence and evolutionary algorithms are reviewed in [44–47]. Parameter tuning of swarm intelligence/evolutionary algorithms through methods like qualitative and quantitative parameters as high-level and low-level hierarchy among parameters has been described in [45]. Review capturing the entire horizon of the research on real-parameter evolutionary multimodal optimization and evolutionary optimization in dynamic environments is presented in [46,47]. Non-parametric procedures for pair-wise and multiple comparison for performance analysis was given in [48].

For the detailed investigation of different PSO versions under adaptive noise cancellation for EEG/ERP, work can be carried out with several hybrid and efficient version of PSO. Hybridization of PSO and differential evaluation is discussed in [49], to improve convergence by modifying the spatial characteristics. Adaptation in PSO according to problem is implemented using non-uniform mutation based method and an adaptive sub-gradient method. This leads to version of PSO known as multiple adaptive methods (PSO-MAM) [50]. Dynamic neighborhood learning particle swarm optimizer (DNLPSO) is based on the modification in selection of best historical value from its dynamic neighbor [51]. This helps in avoiding the premature convergence.

Due to popularity of PSO, several hybrid versions like particle swarm optimization with ant colony optimization (PACO) [52] and PSO with back propagation neural network (PSO-BP) [42] have been developed for application in the field of capacitated vehicle