Neurocomputing 144 (2014) 282–294

Contents lists available at ScienceDirect

Neurocomputing

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

# Improved range selection method for evolutionary algorithm based adaptive filtering of EEG/ERP signals

M.K. Ahirwal [a], A. Kumar [a,*], G.K. 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, 50603 Kuala Lumpur, Malaysia

ARTICLE INFO

*Article history:*
Received 28 August 2013
Received in revised form
13 March 2014
Accepted 10 May 2014
Available online 27 May 2014

*Keywords:*
Differential evolution (DE)
Genetic algorithm (GA)
Bacterial foraging optimization (BFO)
Range selection
Adaptive filtering

ABSTRACT

A frame work for Adaptive Filter/Adaptive Noise Canceller (AF/ANC) design through Evolutionary Algorithm (EA) is presented as an application in Electroencephalography /Event Related Potentials (EEG/ERP) filtering. Process of parameter setting for EA is also explored. A concept of bounded or controlled search space is proposed to identify the best range for search space. Statistical analysis over the simulation results has been performed to quantitatively identify the range and its control parameter. Differential Evolution (DE), Genetic Algorithm (GA) and Bacterial Foraging Optimization (BFO) are implemented for the design of AF. Testing of AF has been done through consideration of two types of noise (white noise and ongoing EEG noise) over three ERP signals (Simulated Visual Evoked Potential, Real Evoked Potential and Real Sensorimotor Evoked Potential).



## 1. Introduction

Evolutionary Algorithms (EA) play an important role in optimizing the solution of engineering, science and technology problem. Today, mostly all the research areas get benefited through application of EAs for their enhancement. Research areas like digital image processing, biomedical signal processing, manufacturing machining processing, robotics, and biology are reported for applied optimization through EAs [1,2]. EAs are easily applicable for those problems, which are modeled as cost function.

Adaptive filter proposed by Widrow is a great achievement in the field of non-stationary signal processing [3]. In the beginning, adaptive filters were designed with the least mean square (LMS) and recursive least square (RLS) algorithm and employed in different fields [4–6]. With the parallel progress and increasing popularity of the EAs, design of adaptive filter has also been reported with EAs. Adaptive filter contributes lot in biomedical signal processing.

Electroencephalography (EEG) signal, a type of biomedical signal, is a bio-electric potential recorded over scalp. Analysis of EEG signal explores various states, conditions and cognitive processes of the brain. Event Related Potentials (ERPs) are sub-class of EEG signal, whose detection and identification is a major aspect in EEG researches [7,8]. Different types of ERPs are generated as a response of various tasks performed by the brain. These ERP get contaminated from various types of noises like power supply noise, other bio-electric signals and also from self-interference [7–9]. Noise removal through adaptive filters has been done for several decades by many researches, to get pure ERP [10–12]. On the same line of research, to get pure ERP, adaptive filters are designed with EAs [13–19].

Optimization through EA works efficiently when their parameters are well tuned. In general, an applicant user may not be aware of the parameter tuning process that causes poor performance of EAs. Every EA has a set of similar parameters and some specific parameters. Various authors use different naming and conventions like qualitative, quantitative, symbolic and numeric parameters are some of the examples [20–22]. Qualitative and Quantitative parameters can be viewed as high-level and low-level ones respectively. Qualitative parameters are those, which define the main structure of an evolutionary algorithm, while quantitative parameters define a specific variant of EA. Quantitative parameters are mostly numerical values which represent instances, while qualitative parameters are often based on certain calculation (like a function or procedure). Statistical approaches have been introduced to help the user of EAs to choose efficient parameter settings [21]. The problem of parameter tuning in EAs has been attempted previously through the methods like racing algorithm, relevance estimation and value calibration, and innovization process for multi-objective evolutionary optimization [23–26].

### 1.1. Problem

Though the designing of adaptive filter based on EAs are very renowned, but parameter tuning of EAs is a major challenge faced

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

http://dx.doi.org/10.1016/j.neucom.2014.05.029
0925-2312/

by the researchers of other domain. It is well known fact that the parameters of EA have significant role in working of EAs, and are also related to their effectiveness. A quantitative parameter defined as "Range of Search Space" is very common to every EA. Poorly tuned or selected search space never gives good results, because if best solution of the problem is out of search space then it is not possible for EA to find it. Hence, Tuning and selection of best range as search space is the problem identified and attempted to solve in this paper through the perspective of applied adaptive filtering in EEG/ERP filtering.

### 1.2. In this paper

A novel frame work has been established based on statistical analysis for range selection of EAs. Problem faced in selection of range are quantified and solved by conversion of quantitative parameter range (R) into qualitative parameter controlled by constant (C) for tuning range of EAs, in form of "R ± C". Consecutively, a novel algorithm is proposed and developed for adaptive filtering of EEG /ERP signals. The proposed algorithm itself has capability of range tuning and adaptive filtering. As reported in the previous work by authors' in [16–19], how best range for problem is identified through the use of "C", but no justification or explanation was provided. In this paper, proper selection of "C" is explained through simulation and justification. For design and analysis of simulation, at first, AF is designed through the Differential Evolution (DE) and Genetic Algorithm (GA). The obtained value of "C" from statistical analysis is also tested on AF based on the Bacterial Foraging Optimization (BFO) algorithm.

The title indicates analysis and application of evolutionary algorithms and algorithm design as the subject matter of this paper. However, most of the considerations rest on simulation and analysis for algorithm tuning for better performance. In fact, several ideas behind followed procedure were also discussed in the end. In turn, many of the concepts introduced here for EAs can be directly transformed to others application areas of EAs.

Rest of the paper is arranged in the following manner: after the introduction in Section 1, adaptive filter and EEG/ERP data used are described in Section 2. EAs applied for AF design, and their simulation and analysis are provided in Sections 3 and 4 respectively. Generalized algorithm and final results for performance analysis are reported in Sections 5 and 6 respectively. At the end, overall work is summarized discussion, conclusion and future work.

## 2. Design of adaptive filter

### 2.1. Adaptive filters

Adaptive filtering design is an iterative technique that attempts to model the relationship between two signals. Fig. 1(a) illustrates the basic structure of an adaptive filter. Pair of input and reference signals and traditional filter design structures (finite or infinite impulse response FIR or IIR filter) is used for implementation. Algorithms for AF design act as a set of rule defined to update the filter coefficients in each iteration. Parameters of algorithm regulate the input to output mapping or computational relationship according to requirement of the designer. As per need of the application, basic structure is modified such as system identification, noise cancellation, channel equalization, and signal prediction models. Noise canceling structure is used in this paper. The concept that modifies the adaptive filter as adaptive noise canceller is depicted in Fig. 1(b) [4–6].

Here, $x(n)$ is the input signal, and $d(n)$ is the reference signal or the desired output signal (some noise component are present in it), while $y(n)$ is the output signal. The error signal is computed by $e(n)=d(n)-y(n)$. The Adaptive algorithm exploits the error signal produced at every instant to update the adaptive filter coefficient vector $w(n)$ in every iteration on the basis of performance criterion. In Fig. 1(b), $s(n)$ is a signal of interest, which is corrupted by a noise component $q(n)$. Pure version of $s(n)$ is the desired signal, but cannot be obtained directly in practice. The noisy signal $s(n)+q(n)$ is employed as a reference signal for the adaptive filter whose input must be the correlated version of $q(n)$, represented as $\tilde{q}(n)$. Filter weights $w(n)$ are adjusted by the algorithm such that filter input signal $\tilde{q}(n)$ is translated as output signal $y(n)$, which is a close estimation of $q(n)$. If $y(n)$ is equivalent to $q(n)$ then, error signal $e(n)$ is equivalent to $s(n)$ in form of $\tilde{s}(n)$.

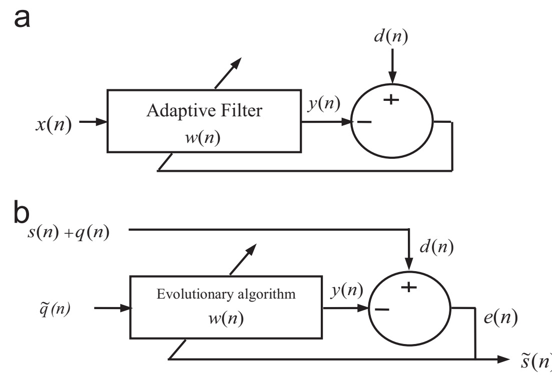


**Fig. 1.** (a)A basic Structure of Adaptive Filter and (b) Adaptive noise canceller with Evolutionary algorithm.

Adaptive filter is generally employed in real time application and one sample time is best for all the system calculations. In the above discussion, linear structure is assumed, nonlinear systems are needed where relationship between $d(n)$ and $x(n)$ is not of linear nature [27]. In case of those system, there are possibly two ways, one is the use of nonlinear filters to compute $y(n)$ and second is the use of nonlinear models or algorithms like neural network, Genetic algorithm, fuzzy logic and others known as non-classical approaches for adaptive filters design [28]. In this paper, non-classical approach is followed by implementing AF through EAs.

### 2.2. Adaptive noise canceller for EEG/ERP

Adaptive noise canceller scheme, depicted in Fig. 1(b), is conceptualized for EEG noise cancellation as illustrated in Fig. 2, where $s(n)$ is the EEG signal (ERP), which is corrupted by the ongoing back ground EEG activity (EEG recorded at other channels) at different noise level $q(n)$. As mentioned above, $\tilde{q}(n)$ is the correlated version of noise, ongoing EEG signals acts as $q'(n)$. It is assumed that the corrupted signal $d(n)$ is composed of the desired $s(n)$ and noise $q(n)$, which is additive and not correlated with $s(n)$. Basically, ANC works based on the estimation of desired output by minimization of error between the desired and actual output. Input for a typical ANC are noisy signal and desired signal, which gives estimate of the desired signal as output. The First order FIR filter is used here. White Noise and Ongoing EEG signal are used as noise. Reasons behind adding white noise and ongoing EEG signal as background noise is described below

#### 2.2.1. White Gaussian noise

WN is added in different ratio to EEG signal because it consists of wide range of frequencies with equally distributed power, and also acts as the worst case for noise contamination. If ANC