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IIR system identification using differential evolution with wavelet mutation

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In this paper an improved version of Differential Evolution (DE) technique called Differential Evolution with Wavelet Mutation (DEWM) is applied to the infinite impulse response (IIR) system identification problem. Instead of fixed value of scaling factor in standard DE, an iteration dependent scaling factor governed by the wavelet function during the mutation process is adopted in the proposed technique. This modification in the mutation process ensures not only the faster searching in the multidimensional search space but also the solution produced is very close to the global optimal solution. Apart from this, the proposed technique DEWM has alleviated from inherent drawbacks of premature convergence and stagnation, unlike Genetic Algorithm (GA) and Particle Swarm Optimization (PSO). The simulation results obtained for some well known benchmark examples justify the efficacy of the proposed system identification approach using DEWM over GA, PSO and DE in terms of convergence speed, plant coefficients and mean square error (MSE) values produced for both the same order and reduced order models of adaptive IIR filters.

1. Introduction

A filter is a frequency selective device, designed and used to extract or enhance the useful portion of information from the signal according to the set values of design parameters. An adaptive system also behaves like a filter with the exception of iteration based coefficient values due to incorporation of adaptive algorithm to cope up with ever changing environmental condition and/or unknown system parameters. The adaptive algorithm varies the filter characteristic by manipulating or varying the filter coefficient values according to the performance criterion of the system. In most of the cases error between input and output signals of the unknown system is considered as the important performance criterion and adaptive filter works toward the minimization of error signal with the proper adjustment of the filter coefficients. Design of such adaptive filter may be alternatively considered as system identification problem. Adaptive filter has got a wide scope of applications in different fields such as communication, sonar, navigation, control, biomedical engineering, seismology, radar and many more. In these fields different types of applications are noticed, namely system identification, inverse system identification, prediction and array processing etc.

Finite impulse response (FIR) and infinite impulse response (IIR) filters are the two types of digital filters. For IIR filter, due to recursive nature, present output depends not only on present input but also the previous inputs and outputs. But in case of FIR filter, the present and past inputs are required to calculate the present output. Hence, more design complexity and larger memory space are demanded for IIR filter optimization problem. But an IIR filter requires lower order compared to FIR filter [1]. In the present work adaptive IIR filter is considered for identifying/modelling an unknown plant.

Previously, as a classical approach of adaptive filtering, Least Mean Square (LMS) technique and its variants are used extensively as optimization tools for adaptive filter. This high acceptance of classical optimization technique is due to the low complexity and simplicity of implementation. But the main drawback of LMS technique is its slow convergence speed to reach the optimal solution. Several measures have been reported to increase the speed [2,3].

In adaptive IIR filtering applications, non-differentiable and multimodal nature of cost function is a major point of concern. Classical optimization methods such as least mean square

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technique are gradient based optimization methods. They are incapable to handle such optimization problems due to following inherent deficiencies:

- Requirement of continuous and differentiable cost function,
- Usually converges to the local optimum solution or revisits the same suboptimal solution,
- Incapable to search the large problem space,
- Requirement of the piecewise linear cost approximation (linear programming),
- Highly sensitive to starting points when the number of solution variables is increased and as a result the solution space is also increased.

Because of the above shortfalls of classical optimization methods, heuristic and meta-heuristic evolutionary search algorithms have got attention for adaptive filtering optimization problems. Different evolutionary optimization techniques aptly used are as follows: genetic algorithm (GA) is inspired by the Darwin's "Survival of the Fittest" strategy [4]; human searching nature is mimicked in seeker optimization algorithm (SOA) [5]; the cat swarm optimization (CSO) is based upon the behaviour of cat's tracing and seeking of an object [6]; bee colony algorithm (BCA) is based upon honey searching behaviour of the bee swarm [7,8]; gravitational search algorithm (GSA) is motivated by the gravitational laws and laws of motion [9]; food searching behaviour is mimicked in bacterial foraging algorithm [10] and swarm intelligence is mimicked in particle swarm optimization (PSO) and its variants [11–20]. Conventional PSO has mimicked the behaviour of bird flocking or fish schooling [1,11,15,16,30,31]; in quantum behaved PSO (QPSO) quantum behaviour of particles in a potential well is adopted in conventional PSO algorithm [18]; in PSO with Quantum Infusion (PSO-QI), a hybridized version of PSO and QPSO in which fast convergence property of PSO and the property of convergence to a lower average error of QPSO have been combined to enhance the performance [13]. In Adaptive Inertia Weight PSO (AIW-PSO), a modified Versoria function is introduced to alter inertia weight of the basic PSO for the improvement of convergence speed and optimization efficiency of standard PSO [14]. To increase the randomness by the process of mutation, a random vector is introduced in the basic QPSO for the enhancement of global search ability [15]. Biological evolutionary strategy is adopted in the development of differential evolution (DE) algorithm [21,22].

Naturally, it is a vast area of research continuously being carried out. In this paper, the capability of global searching and finding near optimum result of GA, PSO, DE and DEWM is investigated thoroughly for GA, PSO, DE and DEWM in identifying the unknown IIR system with the help of optimally designed adaptive IIR filters of same order and reduced order as well. GA is a probabilistic heuristic search optimization technique developed by Holland [23].

PSO is swarm intelligence based algorithm developed by Eberhart et al. [24,25]. Several attempts have been taken towards the system identification problem with basic PSO and its modified versions [11–20]. The key advantage of PSO is its simplicity in computation and a few number of steps are required in the algorithm.

The DE algorithm was first introduced by Storn and Price in 1995 [21]. Like GA, it is a randomized stochastic search technique enriched with the operations of crossover, mutation and selection but unlike GA, stagnation and entrapment to local minima are not associated to it [22].

It has been realized that GA is incapable for local searching [22] in a multidimensional search space and GA, PSO and DE suffer from premature convergence and are easily trapped to suboptimal solution [8,26,27]. So, to enhance the performance of optimization algorithm in global search (exploration stage) as well as local search (exploitation stage), wavelet mutation in association with DE called differential evolution with wavelet mutation (DEWM) is prescribed by authors as an alternative technique for handling IIR system identification problem. The optimal FIR filter design problem using DEWM was reported in Ref. [28].

In this paper the performances of all the optimization algorithms are analyzed with four benchmarked IIR plants and adaptive filters of same and reduced orders. Simulation results obtained with the proposed DEWM technique are compared to those of real coded genetic algorithm (RGA), PSO, and DE to demonstrate the effectiveness and better performance of the proposed technique for achieving the global optimal solution in terms of filter coefficients and the mean square error (MSE) of the adaptive system identification problem.

The rest of the paper is organized as follows: in Section 2, mathematical expression of an adaptive IIR filter and the objective function are formulated. In Section 3, different evolutionary techniques under consideration, namely, RGA, PSO, DE and DEWM are discussed briefly for adaptive IIR filter design problem. In Section 4, comprehensive and demonstrative sets of data and illustrations are given to make a floor of comparative study among different algorithms. Finally, Section 5 concludes the paper.

2. Design formulation

The main task of the system identification is to vary the parameters of the adaptive IIR filter iteratively using evolutionary algorithms unless and until the filter's output signal matches to the output signal of unknown system when the same input signal is applied simultaneously to both the adaptive filter and unknown plant under consideration. In other way, it can be said that in the system identification, the optimization algorithm searches iteratively for the adaptive IIR filter coefficients such that the filter's input/output relationship matches closely to that of the unknown system. The basic block diagram for system identification using adaptive IIR filter is shown in Fig. 1.

This section discusses the design strategy of IIR filter. The input–output relation is governed by the following difference equation [1]:

$$y(p) + \sum_{k=1}^{n} a_k y(p-k) = \sum_{k=0}^{m} b_k x(p-k) \tag{1}$$

where $x(p)$ and $y(p)$ are the filter's input and output, respectively and $n(\geq m)$ is the filter's order. With the assumption of coefficient $a_0 = 1$, the transfer function of the adaptive IIR filter is expressed as given in Eq. (2).

$$H(z) = \frac{\sum_{k=0}^{m} b_k z^{-k}}{1 + \sum_{k=1}^{n} a_k z^{-k}} \tag{2}$$

In this design approach the unknown plant of transfer function $H_s(z)$ is to be identified with the adaptive IIR filter $H_{af}(z)$ in such a way so that the outputs from both the systems match closely for the given input.

In this transfer function, filter order is n and $n \geq m$. In the system identification problem mean square error (MSE) of time samples, J is considered as the objective function, also known as error fitness function, expressed as in Eq. (3).