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Harmony search algorithm for infinite impulse response system identification ☆

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ABSTRACT

In this paper, optimal sets of filter coefficients are searched by a meta-heuristic optimization technique called Harmony Search (HS) algorithm for infinite impulse response (IIR) system identification problem. For different optimization problems, HS algorithm undergoes three basic rules; namely Random Selection (RS), Harmony Memory Consideration (HMC), and Pitch Adjustment (PA) rules, which are inspired from the process that the musicians use to improvise a perfect state of harmony with the consummate skill of blending notes in tune. With the help of the properly selected control parameters, a perfect balance is achieved in exploration and exploitation in searching phases. The detailed analysis of simulation results emphasizes the strength of HS algorithm to find the near-global optimal solution, quality of convergence profile and the speed of convergence while tested against standard benchmark examples for same and reduced order models.

1. Introduction

Adaptive filter plays an important role in prediction, equalization, interference cancellation, system identification and modeling etc. for many different physical systems. Complexity of adaptive filter is increased many folds due to the nature of the physical system, even though scientists are working hard to enrich its vast application fields.

This typical application of adaptive filter for identifying any unknown plant mainly consists of two sections, digital filter and optimization technique. The optimization technique adjusts the coefficient values of the digital filter towards the minimization of error signal generated as the difference of outputs from the unknown plant and the digital filter when the same input is applied to both.

Optimization methodologies are broadly classified as classical and heuristic techniques. Nature inspired heuristic search techniques have proven to be the better alternatives and become the point of attraction for different scientific studies. Nature is a time proven eminent source of principle, concept and methodology for solving various real life computational problems. Few such nature inspired heuristic search techniques aptly used are as follows: Seeker Optimization Algorithm (SOA) [1]; Cat Swarm Optimization (CSO) [2]; Bee Colony Algorithm (BCA) [3]; Bacterial Foraging Optimization (BFO) algorithm [4]; Particle Swarm Optimization (PSO) [5–9]; Quantum behaved PSO (QPSO) [10]; PSO with Quantum Infusion (PSO-QI) [11]; Adaptive Inertia Weight PSO (AIW-PSO) [12]; QPSO with mutation strategy [13]; PSO with Constriction Factor and Inertia Weight Approach (PSOCFIWA) [14]; Differential Evolution (DE) algorithm [15]; BAT algorithm [16]; Gravitational Search Algorithm (GSA) [17] and Adaptive Simulated Annealing (ASA) [18]. Apart from these, different other types of algorithms are applied for various digital filters [19–23].

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In this paper, capability of finding the near global optimal result in multidimensional search space using real coded GA (RGA), PSO, DE and HS is investigated individually and thoroughly for identification of the unknown IIR system with the help of optimally designed adaptive IIR filter of same order and reduced order as well.

GA is a probabilistic heuristic search optimization technique developed by Holland [24]. Eberhart et al. have developed PSO, a swarm intelligence based optimization algorithm [25,26]. One of the most attractive features of PSO is its computational simplicity that has attracted many researchers to apply PSO and its variants to different system identification problems [5–13]. In 1995, DE algorithm was first introduced by Storn and Price [27]. Like GA, it is a randomized stochastic search technique enriched with the operations of crossover, mutation and selection for finding the optimal solution in multidimensional search space.

It has been realized that GA is incapable for local searching [15] in a multidimensional search space and apart from that GA, PSO and DE suffer from premature convergence and get easily trapped to suboptimal solution [3], [16]. So, to enhance the performance of optimization algorithms in global search (exploration stage) as well as local search (exploitation stage), the authors propose an alternative superior technique, Harmony Search (HS) algorithm for the IIR system identification problem.

Hence, in this paper the performances of all above-mentioned optimization algorithms are analysed with eight benchmark IIR plants and corresponding adaptive IIR filters. Simulation results obtained with the proposed HS based technique are compared to those of Real coded Genetic Algorithm (RGA), Particle Swarm Optimization (PSO) and Differential Evolution (DE) and algorithms of other reported literature to demonstrate the effectiveness and superior performance of the HS for achieving the global optimal solution in terms of mean square error (MSE) for unknown system identification problem.

The rest of the paper is organized as follows: In section II, mathematical expression of an IIR filter and the objective function are formulated. In section III, the HS algorithm is discussed briefly for the IIR filter design problem. In Section 4, comprehensive, and demonstrative sets of results with illustrations are given to make a floor of comparative study among different algorithms. Finally, Section 5 concludes the paper.

2. Design formulation

Digital filters are broadly divided into two classes namely; Finite impulse response (FIR) and infinite impulse response (IIR) filters. As IIR filter requires lower order as compared to FIR filter to meet the same specifications [28], hence IIR filter is considered for identifying/modeling an unknown plant.

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

This section discusses the design strategy of an IIR filter. The input-output relationship is governed by the following difference equation [28]:

$$a_0 y(p) + \sum_{k=1}^{v} a_k y(p-k) = \sum_{k=0}^{u} b_k x(p-k) \tag{1}$$

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

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

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

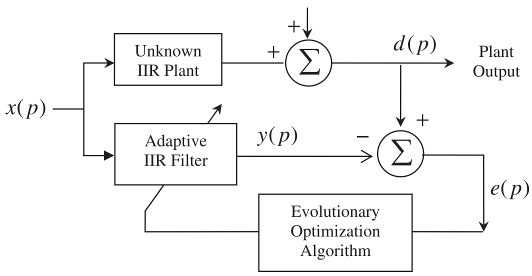

Fig. 1. Adaptive IIR filter for system identification.