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On a cuckoo search optimization approach towards feedback system identification

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ABSTRACT

This paper presents a cuckoo search algorithm (CSA) based adaptive infinite impulse response (IIR) system identification scheme. The proposed scheme prevents the local minima problem encountered in conventional IIR modeling mechanisms. The performance of the new method has been compared with that obtained by other evolutionary computing algorithms like genetic algorithm (GA) and particle swarm optimization (PSO). The superior system identification capability of the proposed scheme is evident from the results obtained through an exhaustive simulation study.

1. Introduction

A pole-zero system can be modeled effectively using an adaptive infinite impulse response (IIR) model with a fewer number of coefficients compared to a finite impulse response (FIR) adaptive model. This capacity of adaptive IIR filters has resulted in making IIR filters popular in diverse fields of applications in signal processing [1,2], including noise control [3]. The error surface in an IIR filter is mostly multi-modal with respect to the filter coefficients. This may lead traditional gradient-descent approaches to fall into local optima. Stability is another concern in IIR filter design. The IIR systems may become unstable if the poles of the filter move outside the unit circle in the z-plane [4].

In order to avoid the local optima problem encountered by gradient descent methods in IIR system modeling, several works have been reported in the literature, considering IIR system identification as an optimization problem solved using an evolutionary computing algorithm [5]. A genetic search approach, which infuses a GA search pattern into LMS algorithm has been used for IIR plant modeling in [6]. The authors have demonstrated the improved identification capability of the genetic search approach over the LMS algorithm based gradient-descent approach. An improved GA with multiple crossovers has been used for identification of band pass and band stop IIR filters in [7]. An eighteen parameter IIR plant was successfully identified using differential evolution (DE) in [8].

In [9], the particle swarm optimization algorithm (PSO), which has evolved as one of the most popular evolutionary computing algorithms [10], has been used for IIR system identification. An incremental PSO (IPSO) has been reported in [11] to achieve improved identification of IIR plants in the presence of outliers in the training samples. The IIR system identification problem has also recently evolved as one of the benchmark problems for testing the efficiency of evolutionary computing algorithms. The cat swarm optimization (CSO) algorithm has been utilized for IIR plant modeling in [12]. A gravitational search algorithm (GSA) based approach has been presented in [13] and an artificial bee colony (ABC) algorithm based scheme has been demonstrated in [14].

The cuckoo search algorithm (CSA), is a recently developed meta-heuristic algorithm, which combines the breeding behavior of cuckoos with the *Lévy* flight seen in some species of birds [15]. CSA has found applications in diverse fields [16] including mechanical engineering [17] and automobile engineering [18]. Also, recent work in [19] has demonstrated the application of CSA for gray level image enhancement. Moreover, [20] emphasizes the use of CSA in tsallis entropy based optimal multilevel thresholding, in the field of image processing. Many researchers have proposed other novel algorithms based on the CSA. A hybrid CSA has been proposed in [21] and [22] presents the inter-species cuckoo search (ISCS) algorithm which incorporates a novel Levy flight pattern. In [23], the authors have shown that CSA performs better than ABC in solving numerical optimization problems and the modified CSA has been reported to converge faster than DE [24]. Thus, CSA could be a potential meta-heuristic algorithm for obtaining higher performance in optimization problems. With an objective to improve the parameter modeling efficiency in an IIR system identification problem, this paper proposes a CSA based IIR system identification scheme.

The rest of the paper is organized as follows. The IIR system identification problem is discussed in Section 2. The steps involved in the cuckoo search algorithm are explained in Section 3. The IIR

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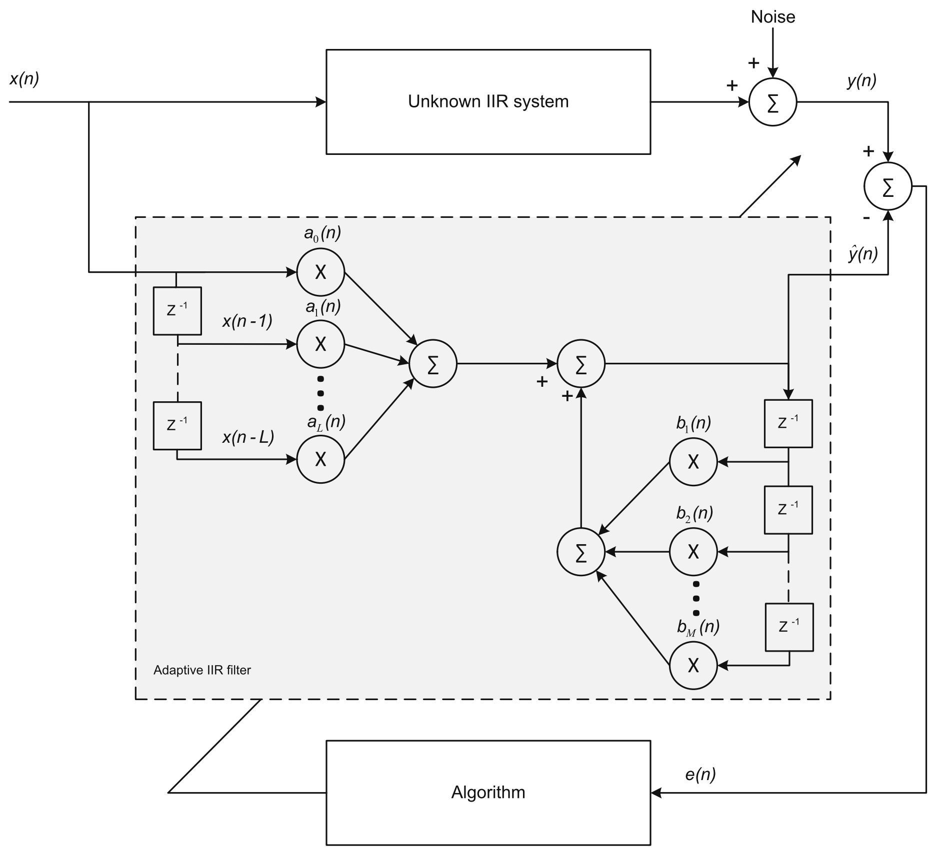

Fig. 1. Schematic diagram of IIR system identification.

system identification problem is formulated as a CSA based optimization problem in Section 4. An exhaustive simulation study is conducted to evaluate the performance of CSA in identifying IIR plants in this section. The concluding remarks are drawn in Section 5.

2. Identification of IIR systems

The IIR system identification problem involves the estimation of the feedforward and feedback parameters of an unknown IIR plant. The schematic diagram of a typical IIR system identification is shown in Fig. 1. If $x(n)$ denotes the input signal to an IIR plant, the z-transform of the output $y(n)$, $Y(z)$ of the IIR plant is given by

$$Y(z) = H_p(z)X(z) \tag{1}$$

where $X(z)$ is the z-transform of the system input and $H_p(z)$ is the transfer function of the IIR plant. The output of the adaptive IIR filter model is obtained as

$$\widehat{y}(n) = \boldsymbol{A}^T(n)\boldsymbol{X_a}(n) + \boldsymbol{B}^T(n)\boldsymbol{X_b}(n-1) \tag{2}$$

where $\boldsymbol{A}(n) = [a_0(n), a_1(n), \ldots, a_L(n)]^T$ is the weight vector of the feedforward path of the IIR filter model at time n and $\boldsymbol{X_a}(n) = [x(n), x(n-1), \ldots, x(n-L)]^T$ represents the tap delayed input signal vector. Similarly, the feedback weight vector is given by $\boldsymbol{B}(n) = [b_1(n), b_2(n), \ldots, b_M(n)]^T$ with $\boldsymbol{X_b}(n-1) = [\widehat{y}(n-1), \widehat{y}(n-2), \ldots, \widehat{y}(n-M)]^T$. The overall transfer function of the IIR model is given by

$$H_m(z) = \frac{A(z)}{1 - B(z)} \tag{3}$$

In a gradient descent IIR system identification approach, the weight vectors $\boldsymbol{A}(n)$ and $\boldsymbol{B}(n)$ are estimated with an objective to minimize $E[e^2(n)]$, where $E[\cdot]$ is the expectation operator and $e(n) = y(n) - \widehat{y}(n)$ is the error in estimation of the IIR model.

3. Cuckoo search algorithm

The cuckoo search algorithm (CSA) is a recent meta-heuristic algorithm, which imitates the behavior of some species of cuckoos [15]. The CSA algorithm has been formulated to provide better performance than traditional meta-heuristic algorithms. In this regard, comparison of CSA with other well-established algorithms like Particle Swarm Optimization (PSO), Differential Evolution (DE) and Artificial Bee Colony (ABC) has been done in [25], and the results suggest that CSA provides more robust and precise solutions.

Cuckoos usually lay their eggs in the nest of some other species of bird, which is termed here as the host bird. In the event of the host bird discovering that the eggs are not its own, it may abandon the nest or may choose to destroy the eggs of the cuckoo. This leads to the evolution of the cuckoo eggs which try to imitate the eggs of the host bird. In the development of the CSA, the following simplifying assumptions were used: (a) The only egg laid by a cuckoo is dumped in a random nest. (b) Only the best nests (with the best egg) will survive and move to the next generation. (c) The number of nests is fixed. (d) p_a is the probability that the host bird will identify the cuckoo's egg. In addition to the breeding behavior of cuckoos, the CSA also combines *Lévy* flight, which are observed in some species of birds and animals. *Lévy* flight refers to a series of straight line flights followed by sudden 90° turns. The implementation of *Lévy* flights has largely been a key factor in improving the CSA performance. In [26], an analysis of *Lévy* flights has been provided using the Markov theory and an explanation has been given regarding the increased efficiency of *Lévy* flights over Gaussian random walks. The steps involved in CSA are as follows: