**IJCTA**, 9(32), 2016, pp. 189-197 ISSN: 0974-5572


# Robust Computational Technique For Optimal Approximation of Discrete time Systems

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**ABSTRACT**

In this paper, optimal model approximation of discrete time systems is proposed. In this proposed method the lower order approximant is obtained by using a mighty evolutionary algorithm called Hybrid Differential Evolution (HDE) with search space expansion scheme which minimizes the different error criterions as fitness functions. The proposed method is simple, effective and gives best approximation of lower order model.The lower order approximant obtained by the proposed method always generate stable model for a stable higher order system.The efficacy of the proposed method is illustrated with a discrete time example of eighth order system.This example is reduced to second order and analyzed by giving impulse input. The simulation results of this proposed method shows a convensing lower order approximants.

***Keywords:*** Hybrid differential evolution algorithm (HDE), integral of squared error(ISE), integral of absolute error(IAE), integral of time multiplied squared error (ITSE), integral of time multiplied absolute error(ITAE).

## 1. INTRODUCTION

In control systems, the designing of the physical models are totally depends on the mathematical models. These mathematical models would resemble the exact characteristics of the physical model and it is a virtual implementation. This mathematical model is designed, because of the realistic model is very expensive,infeasible, and tedious or sometimes some simulation is impossible to conduct on the real model.Accurate model is difficult for understanding, optimizing, controlling and also study of the dynamics of the model. But the simpler model is easy to identify the nature of the model and optimization. This simpler model would be a lower order model, accurate modal is not easy for the applications such as hardware in the loop simulation or embedded model reference control. So that simplicity and accuracy are difficult for the system identification, analysis, optimization and control.

The mathematical model is a physical system is leads to a large scale definitely a simplified engineering model. The analysis and design of controller for such a large scale engineering model is tedious and time consuming. For this type model approximation method is suitable.This model approximation is a mechanism that gives the low accuracy simple model over a high accuracy and complex model. This model approximation method is well-known in the designing of engineering works. It is necessary to have the simplest model from the complex model. Which gives the exact behaviour of the complex model .The model approximation method should satisfy the following properties a) The approximation error shall be small and be with in global error bound b)The procedure should be computationally stable and efficient c)System properties like passivity and stability should preserved in the approximated model.

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Today's modern world is in the race of digitalization by this digital control systems are extensively used rather than analogue control system. Digital control systems are easily mingled or interfaces with Microprocessor by this the significance of discrete time systems are rapidly increased. Discrete time systems are classified in to time domain and frequency domain methods [1]-[2]. The frequency domain [3]-[13] is again classified in to two, based on their approach namely implicit and explicit. The explicit approach is carried out in discrete domain without use of any transformation and this one may not ensures the stability all the time. In the implicit approach uses linear/bilinear transformation model approximation can be accomplished in the transformation domain and finally approximated model is again converted back to discrete domain by inverse transformation. The stability of the original model can be preserved in the approximated model but it not ensures the accurate model.

A plenitude of work has been mentioned in the literature on large scale discrete-time device version approximation over past few a long time. some of the acquainted and latest version approximation methods are Chung, C.G, et al., [3] uses Golub's algorithm to locate the reduced model that can give the authentic minimal factor of the rectangular errors. Bistritz, Y [4] gave an instantaneous Routh stability technique that avoids the bilinear transformation and inherits the beneficial function of balance upkeep. Somnath,P and friend,J [6] had proposed a way on approximate version matching of frequency points within the low frequency sector. Lalonde, R., et al. [5] examine the idea of Least rectangular parameter matching in discrete time systems. Lucas,T.N and Smith, I.D [7] has solved non strong point property of Least-squares Pade method and additionally mentioned in relation to the reduced model's stability. Tewari, J.P and Bhagat, S.K [8] gave a new concept with the aid of the attention of genuine pole of unique system for analysis which leads to more accurate version. The method of Mukherjee, S., et al. [9] overcomes the fundamental concepts like retention of dominant poles, through minimization of mistakes among the step responses of authentic and its approximate model decide the zeros of approximate model. Choo,Y., et al. [10] makes use of unique method primarily based on recursive relationship some of the Impulse reaction gramians to compute approximate version. Chen, T.C., et al. [11] proposed balance equation method that retains the quick poles even as ensuring equal responses at zero time. Ramesh, K., et al.[12] counseled a technique employs the blessings of issue division approach and Pade approximation technique for the discount of range of delayed units and different additives in layout of IIR filters. Narain, A., et al.[13] advised a mixed approach using Fuzzy C-suggest clustering and Pade approximation for higher approximate version. Alsmadi, O.M.okay, et al. [14] technique makes use of the Lyapunov-Sylvester equation with the advantages of minimizing the constant nation errors and keeping the dominant dynamics of the entire order machine inside the approximate version.

Recently Evolutionary techniques were also played a primary role in model approximation of discrete-time systems based on minimization of quintessential rectangular error pertaining to step/impulse input, in which both numerator and denominator coefficients of the reduced model are handled as unfastened parameters within the system of optimization. Mittal, S.ok et al., [15] makes use of the set of rules because of Luss and Jaakola to minimize step ISE. Tomar, S.ok., Prasad,R., et al., in [16] undertake PSO algorithm. real Coded GA become employed by way of Yadav, J.S., et al in [17]. Deepa, S.N and Sugumaran,G makes use of changed PSO algorithm [18]. In [19] uses ABC algorithm to gain a better approximation for big scale discrete-time machine. notwithstanding the enormous number of strategies to be had in specific path, no approach always gives the quality result for all the structures. a number of the authors are nevertheless carrying to a good deal of labor on version simplification of massive scale discrete-time systems which satisfies the retention of balance and accuracy.

In controllor design and analysis approximation is needed to check the system behaviour so that approximation of discrete time systems or model order reduction is a crucial task in controller design.The journey of apprroximation starts in 18th century. In 1807 Fourier (1768-1830) published the idea to approximate a function with a few trigonometric terms. In linear algebra the first step in the direction of model order reduction came from lanczos (1893-1974). W.E. Arnoldi realized that a smaller matrix could be a good approximation of the original matrix. In general the available control systems are in higher order. It is impossible to analyze and synthesize of higher order system, so that to reduce the order or approximation of systems is necessary in every control area applications .while approximating means need to preserve the characteristics of original system

There are many methods available in the literature to give the approximation of the systems. They are categorized in to two performance –oriented model approximation and non-performance oriented model approximation. These techniques can trust massively on a numerical depletion engender and an efficacious algorithm for classifying the performance criterion for retrieve optimal approximation models with diminishing $H^{\infty}$-norm or norm. In the biography of approximation, the ecumenical solution is accomplished through detecting the foremost order optimality condition by a homotopy continuation method. However, it is unfit for unstable systems complexities are regularly encountered if an$L^{\infty}$- norm or $H^{\infty}$-norm choose as the appearance index of model approximation because neither$H^{\infty}$-norm or $L^{\infty}$-norm is contiguously dependable always and proficient numerical methods of criticizing and minimizing an$H^{\infty}$ or $L^{\infty}$ norm are still vanished. In order to overcome the limitations of the existing methods, in this paper a robust computational technique for approximation of linear systems is developed. This article is tabulated as ensues

Many methods are available in history of model order reduction (or) optimal approximation in that, some of the methods are for continous domain and some of them are discrete domain[20]-[25]. Some of the renoven methods are model order reduction by matching markovs parameter[26]. It is introduced to ensure stability. A famous technique for optimal approximarion in dicsrete domain is krylov subspace method[27]. In this the stability of the apprimated system is not gurantee the satbility of the system i.e. it may gives unstable system for stable systems. Not only this there are many other techniques are available based on the reduction styles. Some of the techniques are based on eigen value preservation,and some of them are transfer function reduction (point matching), reduction via moment matching. Not only this there are some other new optimizing techniques are available that are particle swarm optimization[28]and artificial nueral networks[21] been introduced for optimal approximation of discrete domain systems

## 2. PROBLEM STATEMENT

It is prominent in the control society that an intricate dynamic system can be competently expressed by a low–order transfer function with a time delay. Hence, given a higher order rational or irrational transfer function G(s), it is want to find an approximate model of the form

$$H_m(Z) = \frac{b_0 Z^n + b_1 Z^{n-1} + .............. + b_n}{Z^n + a_1 Z^{n-1} + ................ + a_n} \tag{1}$$

So $H_m(Z)$ enclose the thirst to have characteristics of the present system G(Z). In this solicitation, we have intention to discover an optimal approximation model .

ISE: $$\sum_{i=0}^{N} \left| G(j\omega_i) - H_m(j\omega_i) \right|^2 \tag{2}$$

IAE: $$\sum_{0}^{N} | G(j\omega_i) - H_m(j\omega_i) | \tag{3}$$

ITSE: $$\sum_{0}^{N} T \,|\, (G(j\omega_i) - H_m(j\omega_i)) \,|^2 \tag{4}$$

ITAE: $$\sum_{0}^{N} T \left|(G(j\omega_i) - H_m(j\omega_i)\right| \tag{5}$$

Is diminished, the frequency values of $\varphi_i$, are ranging as $\varphi_i$ = 1, 2, ….., N, and the integer N chooses a priori. In this concern the present system G(Z) is asymptotically stable, and the constraint as follows

$$H_m(o) = G(o) \tag{6}$$

To a certain the steady state replications of the present system and the approximate model are identically clone for unit step input

The quandary of diminishing J given in (2) is an optimal parameter called quandary. In the present solicitation, we shall apply the direct search of hybrid differential evolution algorithm to find the paradigmatic parameters $a_i$, $b_i$ =1, ….., m-1, and $\tau_d$. It is noticed that because of the vanish of the exact erudition around the premises within which the optimal parameters locate, we blend a search space expansion scheme into hybrid differential evolution. A short and sweet description of such a hybrid differential evolution is provided in section III.

## 3. HYBRID DIFFERENTIAL EVOLUTION

### 3.1. Population Initialization

The HDE algorithm is commenced with engendering a population $N_p$ of authentic valued n dimensional vectors

$$x_{j,k} \in [\underline{x_k}, \overline{x_k}],\ k = 1, 2, \ldots, n. \tag{7}$$

The fundamental parameter values are chosen from within user defined bounds

$$x_{j,k} \in [\underline{x_k}, \overline{x_k}],\ k = 1, 2, \ldots, n. \tag{8}$$

It is noted that the search region or interval $[\underline{x_k}, \overline{x_k}]$, set by a user for the parameter $x_k$ may be more minute than, but with in, the allowable interval $(x_k^-, x_k^+)$ in the case of $x_k^- = -\infty$ and/or $x_k^+ = +\infty$. Once the initial population is engendered, the cost of each population vector is evaluated and stacked for future reference.

### 3.2. Mutation

The summing of differential vector to a population vector is known as mutation. In this HDE algorithm, a population vector $X_\alpha$ is mutated into $z$ $[z_1, z_2, \ldots\ldots\ldots Z_n]^T$ by summing to $X_\alpha$ the weighted difference of two desultorily called but different population vectors $X_\beta$ and $X_\gamma$, i.e.,

$$Z = X_\alpha + F_s \cdot (X_\beta + X_\gamma) \tag{9}$$

Where $F_s$ is a scaling factor in the interval (0, 2). The mutated vector z will be utilized as a donor vector for engendering a trail vector.

### 3.3. Crossover

Engendering a trail vector by superseding specific parameter of the target vector by the according parameter of arbitrarily engendered donor vector is called crossover. The crossover rate $C_r$ justifies when a parameter should be subplant. The phenomenon of engendering a trail vector $X_t = (x_{t,1}, \ldots, x_{t,n})^T$ from the target vector

$X = (x_1, ..., X_n)^T$ and the donor vector Z is beginned with engendering a set of N arbitrary numericals which are distributed systematically in the interval (0, 1). Next, a set of N non uniform binary sequence is engendered by letting

$$b_i = \begin{cases} 1 & if \quad r_i \le C_r i = 1, 2..., n. \\ 0 & otherwise. \end{cases} \tag{10}$$

Then each element of the trail vector $X_t$ is taken as

$$x_{t,k} = \begin{cases} x_k & \text{for } \mathrm{b_k} = 1 \\ z_k & \text{for } \mathrm{b_k} = 0. \end{cases} \tag{11}$$

Once the trail vector is fixed, its cost is estimate and collated with the coinciding target vector. The target vector is superseded by it in $t_r$ in next engender .If its cost is more immensely colossal that of the trail vector.

### 3.4. Selection

The phenomena of engendering best progeny is called selection.The cost of each trail vector$X_t$ is similitude with that of its parent target vector $X_i$. If the rate of the target vector $X_i$ is diminished value that of the trail vector, the target is empowered in lead to the next offspring contrastive, the target vector is superseded by the trail vector in the next off spring.

### 3.5. Migration if necessary

The next step after the selection in HDE is Migration. The main aim of migration is to branch out a population that failed in actual tolerance besides eluding from local optimal and averts premature conjunction. The incipient populations are predicated on the best individuals. The $h^{th}$ genre of the $i^{th}$ individuals as follows

$$X_{hi}^{G+1} = \begin{cases} X_{hb}^{G+1} + \rho_1(X_{h\min} - X_{hb}^{G+1}), \ if \quad \rho_2 < \dfrac{X_{hi}^{G+1} - X_{h\min}}{X_{h\max} - X_{hb}^{G+1}} \\ X_{hb}^{G+1} + \rho_1(X_{h\max} - X_{hb}^{G+1}), \ otherwise \end{cases} \tag{12}$$

Where $\rho_1$, $\rho_2$ are desultorily engendered numerous uniformly distributed in the range of [0, 1]; h = 1, ….., $N_c$. The migration in HDE is executed only if assesments fails to match the desired steadiness of population diversity. This quantification Is defines as follows.

$$\rho = \sum_{\substack{i=1 \\ i \ne b}}^{N_p} \sum_{j=1}^{n_c} X_{ji} \Big/ n_c(N_p - 1) < \varepsilon_1 \tag{13}$$

where

$$X_{ji} = \begin{cases} 1, \ if & \left| \dfrac{X_{ji}^{G+1} - X_{jb}^{G+1}}{X_{jb}^{G+1}} \right| > \varepsilon_2 \\ 0, \ otherwise \end{cases} \tag{14}$$

The hybrid differential algorithm as follows

**Table 1**
**Different Values of the Hde Variables Used in Example**

| *Parameters* | *Value* |
|---|---|
| Population size, $N_p$ | 50 |
| Maximum number of generations, $N_i$ | 500 |
| Search space checking period, $N_c$ | 10 |
| Search space expansion factor, γ | 1.2 |
| Crossover constant, $C_r$ | 0.6 |
| Mutation scaling factor, $F_s$ | 0.7 |

1. Adopt control variables of optimization process that are population size, scaling factor, crossover probability, convergence criterion, number of problem variables, lower and bounds of variables and maximum number of iterations. establish an initial population entity with random positions.

   $$X_{i0} = X_{\min} - X_{\max} - X * rand$$

   The value of fitness function is to be calculate for every parameter.

2. The fitness of each particle with personal best (Pbest) is to be correlated. If current result is better than Pbest then replace Pbest by current solution.
3. The fitness of all species with global best (Gbest) is distuinguished.If the fitness of any particle is better than Gbest, and then replace Gbest.
4. A new parameter is engendered with weighted difference between two vectors to a third vector Mutant vector is engendered based on the current individuals

   $$Y_i^{G+1} = X_i^G + F\left(\left(X_{r1}^G - X_{r2}^G\right) + \left(X_{r3}^G - X_{r4}^G\right)\right)$$

5. A new vector called trailed vector is obtained by the combining of mutant vector and target vector the combining or mixing of parameter is called crossover Each generation of $i^{th}$ individual is reproduced from mutant vector and present individual

   $$Y_i^{G+1} = \begin{cases} X_{hi}^G \\ Y_{hi}^G \end{cases} \text{; if a random number >CR}$$

   ; otherwise

6. All the parents are have chance to select as a solutions in the population with the irrespective of their fitness value.
7. Crossover and mutation evaluates the children. If the performance or fitness of the offspring is compared with the fitness of parent vector. If offspring or children have best fitness value then the parent is replaced by its offspring.
8. To get desired fitness value rerun steps 2 to 7.

## 4. ILLUSTARTIVE EXAMPLE

The robust-nous of this algorithm can be explained by a example which is a discrete time system [30] the transfer function of that system is as follows

$$G_7(z) = \frac{(2.0434Z^2 - 4.98255Z^6 + 6.57Z^5 - 5.8189Z^4 \quad +3.636Z^3 - 0.00088Z^2 - 1.4105Z + 0.2997)}{(Z^7 - 2.46Z^6 + 3.433Z^5 - 3.333Z^4 \quad +2.546Z^3 - 1.584Z^2 + 0.7478Z - 0.252)}$$

This system is desired to bring second order and is reduced to second order by using HDE [34, 35] this HDE is from DE [32, 33] the only difference between is migration the strategy is population in diversity, In this algorithm the impulse response is to be consider and compared for analysis .This analysis is done for various fitness functions like ISE, IAE, ITSE, ITAE to get the better fitness function for this example, The reduced order i.e. second order is as follows

$$G^{*}{}_{2}(Z)=\frac{0.02113Z^{2}+0.1226Z\ \ -0.06367}{Z^{2}-1.759Z+0.8335}$$

The above second order can be obtained by HDE

$$G_{2}(Z)=\frac{0.022Z^{2}+0.023Z\ \ -0.064}{Z^{2}-1.76Z+0.833}$$

This second order is obtained by GA taken from[30].

However these two reduced second order models are same by observing a slight variation is there in reduced order transfer function in model order reduction this slight variation is also countable in better approximation if we observe the impulse response the GA reduced order and HDE reduced order below figure 1.1.

In literature many of the others solved this example by converting this discrete time system in to continuous domain, [29] solved this same example is continuous domain via state space model ,in this HDE this is solved in discrete domain only via transfer function model the impulse response of the above example is as given below

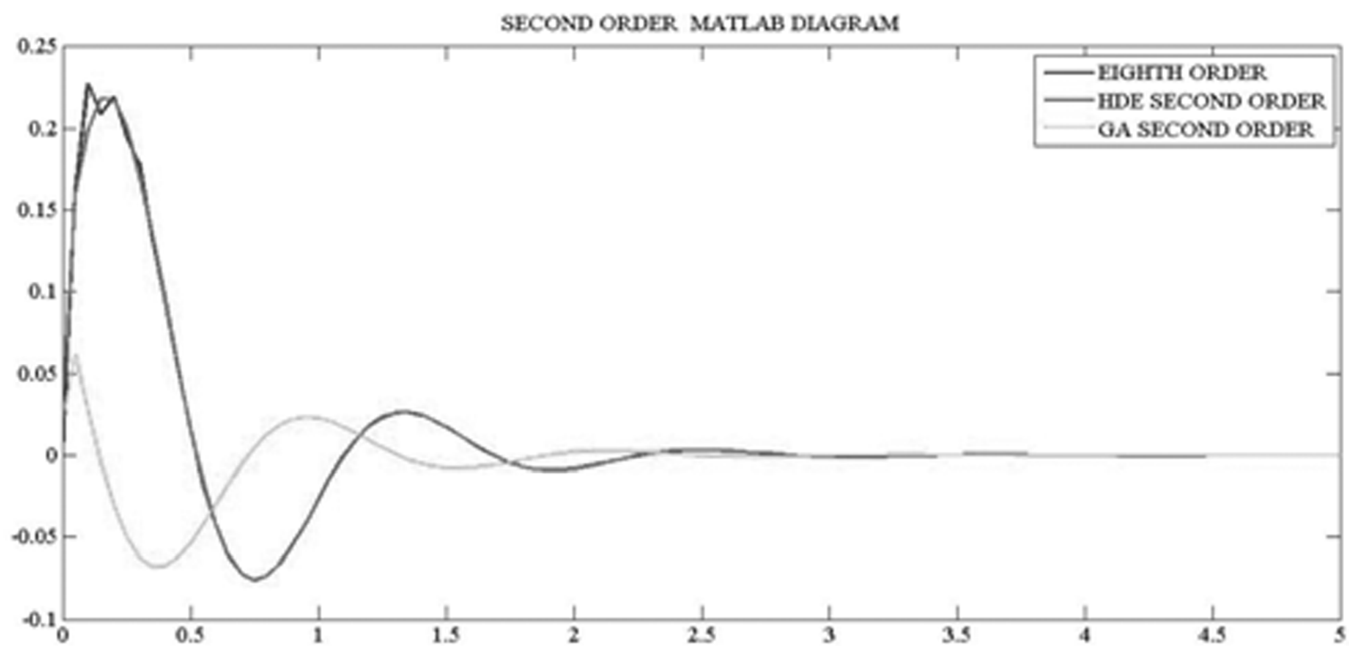


**Figure 1: Comparison of impulse responses of eighth order and second order with GA and HDE**

**Table 1**
**Collation of Different Performance Indexes**

| | | *ISE* | *IAE* | *ITSE* | *ITAE* |
|---|---|---|---|---|---|
| HDE | Second order | 0.0014 | 0.0807 | 0.00014 | 0.0081 |

This example is examined by different performances indexes like ISE,IAE,ITSE,ITAE and the better optimum value is obtained by ITSE the comparison various performance indexes is in table II

## 5. CONCLUSION

Hence from the figure1 and Table 1 in figure1 the impulse response of original order and reduced order is compared between GA and HDE the HDE impulse analysis is very close to the original order i.e. eighth order but where as impulse response of GA is not closer to original order but if we observe the reduced order transfer function the both are same and is confused like twins but the impulse response shows the difference between them. Not only this different performance indexes like ISE,IAE,ITSE,ITAE are checked to get the best fitness value this can be obtained by ITSE. So finally HDE gives the better approximation and best fitness value.

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