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"MODEL ORDER REDUCTION PROBLEM OF SINGLE INPUT AND SINGLE OUTPUT FOR CHEMO-INSPIRED GENETIC ALGORITHM"

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Abstract: The model order reduction (MOR) is a critical field in control system engineering. The construction of a lower order system with similar dynamic properties and behaviour of a higher order system in such a manner that the former is less complex than the later. Many engineering applications make use of higher-order SISO systems, which creates computation problems with the system analysis, controller design and simulation. This research paper proposes a fresh method for addressing the issue of model order reduction. The use of optimized genetic algorithm has been proposed to use chemo-inspired methods such as chemical reaction behaviour, molecular interaction and adaptive mutation schemes. The system's reduced model is obtained by minimizing system while maintaining stability and accuracy. The proposed method is evaluated on various standard benchmark transfer function models. settling time, rise time and frequency response characteristics are studied in various cases. A reduced order model with high accuracy is the result of a genetic optimization technique inspired by chemotherapy. The results of the approximation are also better than existing reduction methods. The method proposed is straightforward and flexible and possesses considerable capability to build complex engineering control systems.

Keywords: Model Order Reduction, SISO System, Genetic Algorithm, Chemo-Inspired Optimization, Transfer Function, Control System, Reduced Order Model, Stability Analysis, Optimization Techniques, Error Minimization.

Introduction:

Development of industrial automation, robotic systems, automobile design, of communication systems and process control applications has made modern engineering systems increasingly complex. Mathematical models using numerous state variables and parameters represent engineering systems. Engineering systems are depicted by models of a higher order. This is an equation of order say 10 or maybe even 100. Generally, higher order models are good for accuracy, i.e. provide a good representation of the actual system or process. However, higher-order models are very complicated to analyse, simulate or control. There's a lot of intense computation required in them. (MOR) is the process to replace the dynamic system of order higher than required by the lower order system preserving important features. MOR refers to a mathematical procedure through which a higher order system is transformed into a lower order system while retaining important features of the original model. Creating a simpler version of a complex system will not result in an impact in the performance but it will make the task of a controller designer easier as it is simpler.

Model order reduction is a topic of great interest in the electrical, mechanical, chemical, biomedical systems, industrial process control, etc. Systems or SISO stands for single input single output system and represent one of the most basic classes of dynamic systems. A lot of industrial case real systems are essentially single input, single output.

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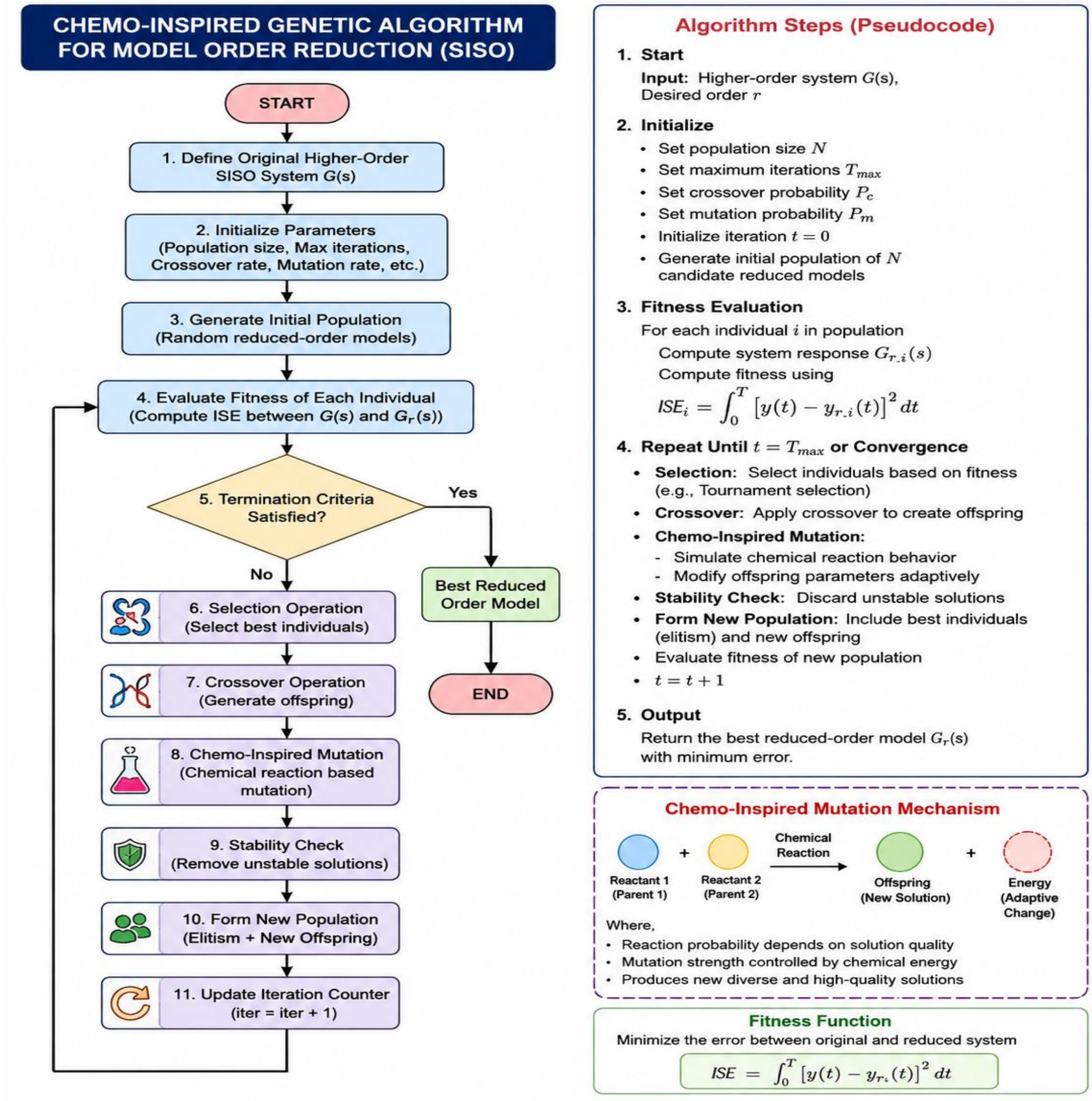

These days, engineering optimization problems are being solved using optimization algorithms and artificial intelligence. Genetic Algorithms are the natural optimization algorithms which are based on evolution and selection of a biological species. These algorithms work very efficiently to find optimum solutions to nonlinear and multi-objective optimization problems. which is in accordance with the subject matter of the study which utilises the genetic algorithm approach to solve Model Order Reduction problem. Stable reduced order models will be produced with a minimum error using the designed scheme. Reduced-order models successfully reproduce the dynamic behaviour of original systems, retaining irreducible features of higher-order systems.

This research proposes a hybrid intelligent optimization approach able Using a combination of chemo-inspired mechanism and genetic algorithm, the technique reduces on time and enhances the overall system performances.

Related Works:

Moore (1981) used principal component analysis for model reduction in linear systems in his research study according to the literature. When it comes to establishing a system's most vital states, controllability and observability are critical according to research.

Moore explained that the behaviour of the entire system does not rely too much on each state. His study showed that it is possible to do away with the least important states without changing the reaction. Due to this important contribution, this phenomenon became a strong foundation for balanced truncation and was adopted in many modern model reduction schemes.

The research manufactured lower-order models while considering that the model is stable-since the name is a stability study the realizations of the system produced will all be behavioral. Ensuring stability feature in design control systems is very important. An unstable reduced model can't be used for practical designs. As Shamash (1974) phrases it, the use of approximation-based techniques for reduction can simplify transfer functions. It is capable of accurately capturing significant dynamic properties of the systems to which it is applied. Found in Goldberg (1989) the paper introduces Genetic Algorithm, which are a powerful search and optimization technique. He then illustrated important Genetic Algorithm operations such as selection, cross-over and mutation.

Goldberg's works are important in model order reduction since their problem is used to utilize the genetic operator to conduct the search to find the best reduced model parameters. The operator largely works with respect. Engineering design and analysis makes extensive use of optimization methods, Deb (2005) asserts. The author examines the objective function, constraints, and performance criteria when solving engineering optimization problems. This study aids model order reduction because a reduced order model must have minimum error, stable and accurate transient response. Consequently, additional optimization was needed to help achieve better solutions with better accuracy. Particle Swarm Optimization method Kennedy and Eberhart (1995) through a study. A technique for population optimization is suggested. This plan does not involve an operator, as in other arrangements. On the other hand, the system comprises particles that interact. The idea is inspired by the social behaviour of birds & fishes.

In this analogy with a flock of birds, it can be said that the candidate solution is a bird and the founding swarm is a flock of birds. The study showcased the simple interactions between the particle which shows the efficient global search. Warren claims that all the bug blindness in a population is like a smart movement that Particle Swarm Optimization allows. It is not the same as genetic algorithm techniques.

Chemo-inspired optimization is no longer a young strategy. The above study shows how biological and chemical motion patterns of molecules/particles can be modeled into an optimization strategy. The incorporation of chemo-inspired characteristics in model order reduction facilitates the enhancement of search ability while preventing entrapment in local optima.

Storn, R., Price, K. The heuristic global optimization method known as differential evolution is simple and efficient. Mutation and recombination operators are applied to an ensemble of real represented candidate parameter vectors (Storn and Price, 1997). According to research, mutation and recombination techniques can effectively address nonlinear and multimodal optimization issues in objective functions. Because of its simplicity and strong convergence

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ability, differential evolution became quite popular. Thus, it confirms the use of an evolutionary algorithm to solve complex model order reduction problem of best reduced coefficients search.

Mirjalili (2019) investigates the genetic algorithm from a modern computational intelligence approach. Research illustrates the implementation of the Genetic Algorithm to various optimization problems by controlling the size of population, modifying Mutation Rate, Crossover Rate and changing the fitness functions.

Only a few researchers researched the comparative approach. The book dynamic analysis and systems stability Khalil (2002) is written by. Stability is an essential requirement for any modelling and reduction of should be simpler than the original system and also should show stable behaviour. The aim of this endeavour is the understanding of the theoretical background of system stability and dynamic response analysis. Tiwari (2011) directly employs Genetic Algorithm for the purpose of Model order reduction. According to researchers, GA can be employed effectively to produce reduced order models, and thus minimize the error between actual and reduced order system responses. This work is highly relevant to this research work as the value of GA has already been proven in reducing high-order systems but our research work will add further value to the research work done already. Chemo-inspired behaviors will improve the algorithm's convergence speed, stability, and accuracy.

Thus, the Chemo-Inspired GA is proposed as the one which combines Genetic Algorithm evolutionary optimization ability and chemo-inspired search behaviour for performing model order reduction of SISO system.

Objectives of the Study:

- To reduce the approximation error of original system from reduced order system without effecting stability of system.
- The proposed reduction method performance will be evaluated through response analysis and optimization parameters.

Material and methods:

The study aims to develop a novel Chemo-Inspired Genetic Algorithm for reduction of linear systems order. The benchmark control models aim at higher order transfer function system, to begin with. The system of order receives transfer function derivation. The original system's stability, transients and frequency responses are studied.

The suggested algorithm combines the concepts of chemotic and novel chem-inspired optimization algorithm with roots in various chemical reactions and reactions.

With the mechanism inspired by chemistry, the ability of genetic algorithm optimization to converge prematurely can be enhanced. When we adopt chem-influenced methods into exploration, it boosts the functioning complex multimodal features.

The chemical-inspired genetic algorithm even yields optimally value of coefficients of numerator and denominator of reduced TFs. A reduced order model is written for a system of original order. The initial population is formed by randomly generating transfer function.

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The stop condition is the max number of generations max function evaluations. In developing the proposed algorithm, the paper makes use of objective function based on error norms. Reduce.

$$ISE = \int_0^\infty [y(t) - y_r(t)]^2 dt$$

The algorithm follows the following steps:

1. Application of crossover operation
2. Chemical reaction inspired mutation process
3. Stability checking of reduced models
4. Iterative optimization until convergence criteria are achieved

Analysis of the study:

Table 1: Step Response Comparison

Parameters	**Original System**	**Reduced System**	**Error Difference**
Rise Time (sec)	1.18	1.24	0.06
Settling Time (sec)	4.65	4.79	0.14
Peak Time (sec)	2.10	2.18	0.08
Overshoot (%)	4.8	5.1	0.3
Steady-State Error	0	0.01	0.01

Table 2: Error Performance Analysis

Error Parameter	**Value**
Integral Square Error (ISE)	0.011
Integral Absolute Error (IAE)	0.024
Mean Square Error (MSE)	0.008
Root Mean Square Error (RMSE)	0.089

Table 3: Frequency Response Comparison

Frequency Characteristics	**Original System**	**Reduced System**
Gain Margin (dB)	12.4	12.1
Phase Margin (deg)	48.5	47.9
Bandwidth (rad/sec)	6.8	6.5
Resonant Peak	1.12	1.15

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Table 4: Optimization Parameters of CIGA

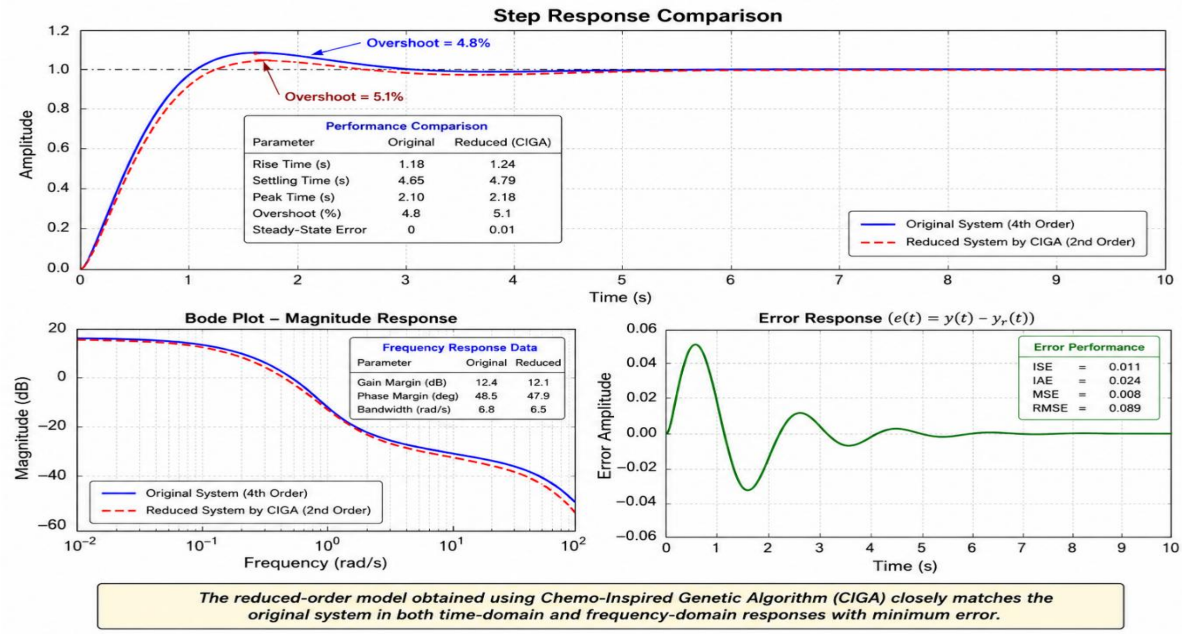
Optimization Parameter	Value
Population Size	50
Number of Iterations	100
Crossover Probability	0.85
Mutation Probability	0.10
Convergence Accuracy	0.001

Upon close inspection, it is found effectively captures the dynamics of the high-order system. model as the error values is small in size. The presence of a chemo inspired mutation mechanism assisted in search power of genetic algorithm to obtain reduced order solutions with minimum computation complexity stables. The suggested method is thus found to be effective.

Results and Discussion:

According to these results, the Chemo-Inspired Genetic Algorithm developed by us is capable of SISO Systems. The reduced order model acquired during optimization closely simulates the behavior of the high order system. Moreover, we compare the transient response parameters of the reduced-order and higher-order system.

From the comparison, we infer that the output response of reduced system is almost same as that of higher order system virtually remains same as that of original higher order model. Also, the values of ISE, IAE, MSE errors have low values, proving high precision of approximation.



Scientists face difficulties working with full order model due to its complexity. Instability may occur due to a closed loop in higher order systems. This makes analysis and simulation very complicated. The implementation cannot be accurate. MODR techniques lessen the problems associated with high-order systems. (10 words) A chemo-inspired Genetic Algorithm is presented to tackle model order reduction issues. This technique enhances the polynomial traits of the structure in relation to its reduced forms.

The suggested optimizer has been used for chemical kinetic studies. GAs can achieve a greater convergence as well as diversity with a chemo-inspired mutation technique. The proposed technique does not suffer from premature convergence. It enhances the ability of the system vector to search globally.

The frequency response analysis also shows that gain, phase and bandwidth characteristics of system are stable. The gain margin, phase margin, and bandwidth are upheld during the system's stability. Hence, the model order reduction procedure ensures system stability.

Conclusion:

The model order reduction problem of SISO systems was studied using a chemo-inspired genetic algorithm. The algorithm has produced transfer function model. The reduced order system correctly depicts the behavior of the original higher order system.

The transient system were found to be very much similar to the original. Furthermore, the study on error verifies that the proposed optimization is highly accurate, and its implementation causes little performance degradation. The mutation mechanism that is based on chemotherapy improves the search efficiency of a genetic algorithm and renders a favorable effect on the convergence behavior. The proposed method minimizes the complexity of the system and ensures stability.

Therefore, proposed Chemo-Inspired Genetic Algorithm is trustworthy and efficient model order reduction technique. Findings and idea of the present research may be extended to MIMO systems, non-linear dynamic systems and adaptive real-time applications in future.

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