MODEL REDUCTION AND CONTROLLER SYNTHESIS OF HIGHER-ORDER ASYNCHRONOUS MOTOR WITH NEW CHAOS BASED GORILLA TROOP OPTIMIZERS (CBGTO)

ABSTRACT

In this work, 50 new chaos based gorilla troop optimizer (CBGTO) is proposed. Different one-dimensional chaotic maps can be used to alter the controlling parameters in the parent algorithm. A 5th order induction motor model is utilized to test the effectiveness of the proposed techniques. In addition, an intelligent PID controller is constructed using the same method in an approximation model matching framework. Existing standard and cutting-edge methods are outperformed by the new methods in terms of convergence speed and precision.

Keywords: Gorilla troop optimizer (GTO), chaos based gorilla troop optimizer (CBGTO), chaos, delta transform theory, intelligent controller design.

Background of work:

Due to their strength and endurance, induction motors are used in a range of sectors. Induction motors account for more than 80% of all industrial motors. Additionally, they require less maintenance. Further, they are easily accessible and reasonably priced [1].

However, their mathematical models frequently lead to overly complicated systems that are challenging to control and run effectively. Without a doubt, they call for higher-dimensional controllers. Thus these systems could require the purchase of additional hardware in order to obtain higher-order controllers, which is not always a wise decision. Thus, the order of the initial system must be lowered [2].

There are various benefits to modelling and managing discrete-time systems using delta operators. It is important to note a few of them in this document. Owing to the fact that the shift operator based discrete-time systems cannot handle fast digital data, numerical ill-conditioning occurs in these systems. The delta domain operator, however, guarantees quick and accurate calculations. Discrete delta systems can be modelled as continuous time systems due to the small sampling time [3].

Metaheuristic methods are frequently used to model and regulate a variety of systems in the delta operator framework [4-6]. In recent years, more engineering problems have been solved using chaotic metaheuristic methods. There are many ways to introduce randomization into metaheuristic methods. The position update rule is typically changed at random to enhance the performance of the original algorithm. Further, the overall performance of the metaheuristic methods can be improved by using chaos maps. New algorithmic structures can be created using chaos maps in place of random numbers varying between 0-1 [7-8].

The gorilla troop optimizer (GTO), a revolutionary metaheuristic technique, was motivated by the social intelligence of gorillas [9]. There are several ways to enhance the performance of this algorithm. One such well-liked option is the chaotic

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variation. This paper proposes a chaos-based gorilla troop optimizer (CBGTO) based on previously published chaos maps. Two crucial regulating factors can be randomly changed to improve the performance of the algorithm. Also chaotically altered are some of the random number generators employed in this approach. A 5th order induction with 50 horsepower is used for the initial testing of these algorithms. Thus, induction motor with 50 hp rating is modelled and controlled using these novel methodologies.

The remainder of the paper is structured in accordance with this. Section 2 deals with the problem statement for the reduction of the system into lower-order models and the development of the controller. A novel gorilla troop optimizer, coined as CBGTO, is developed using chaos maps in Section 3. A 50 hp induction motor model is optimized using the developed CBGTO techniques, and the results are shown in Section 4. The major inferences of this investigation are outlined in Section 5.

Definition of the problem:

A discrete-time system based on a shift operator parameterized continuous-time system fails to produce usable information when sampled at a very high sampling rate. The delta operator, another discrete-time operator, is also available. The results for a delta operator parameterized discrete-time system can be obtained with ease at a very high sampling rate. While constructing the discrete domain controller, this work takes advantage of the delta operator's superior property as well [10].

Two independent approaches are performed to solve the problem given in this research. Before proceeding to the controller synthesis, the model order must be reduced. A second-order model with fixed structure is considered during the model reduction method. In this lower-order model, the four decision variables are optimized. A higher-order model is compared using the response of a lower-order system with unknown parameters. For comparing the responses, a pseudo random binary sequence (PRBS) is used as an input. A lower-order system is developed by minimizing the integral of time-weighted absolute error (ITAE). To achieve a fixed-structured, reduced system, the following conditions must be met:

- Achieving a steady-state gain similar to the original test system
- Stability is preserved in the resulting second-order model
- Maintaining the original system's minimum phase nature.

To minimize the model for the integration of discrete and continuous-time systems, we use the delta operator framework. Following that, an intelligent PID controller is also proposed for the simplified system. The controller is built using design standards for approximate model matching (AMM) [11]. AMM is favoured over exact model matching (EMM) because it ensures that the controller will be physically realized. Any unknown controller settings can be determined using the AMM's reference model idea. The controlled plant's closed-loop response is measured using an established reference model derived from literature. In order to identify the controller parameters, the square error must be minimized. PID controllers are utilized to do this. It will be identical to the reference test system's step response in the delta domain. Using the advantages of AMM and the delta transform theory, Section 3 offers a new chaos based gorilla troop optimizer (CBGTO) for the delta domain modeling and determination of the controller parameters. Standard heuristic procedures for comparison also include the GTO method long with some latest methods.

Method of study:

The Gorilla Troops Optimization (GTO) model simulates five techniques based on the dynamic behaviour of the gorilla group. These tactics include the migration to an unknown territory, migrating to other gorilla group, following the silverback, and competing for adult females. These are imitated and exhibited to demonstrate how the optimization method is investigated and applied. During the exploration phase, three tactics are used: migration to an unknown area, mobility with other gorillas, and migration in the direction of an identified location. During the exploitation stage, the silverback is pursued and adult females are competed for [9].

Almost all metaheuristic algorithms with stochastic elements generate randomness by employing probability distributions, which are typically uniform or Gaussian. In theory, chaotic maps may be preferable to these types of random maps since chaos can have many of the same qualities as randomness but better statistical and dynamical properties. This type of dynamic mixing is necessary to ensure that the algorithm can generate solutions that are distinct enough to reach all of the modes in the multimodal objective landscape. Thus, chaotic optimization refers to how chaotic maps are employed to substitute random variables. Due to the ergodic nature of chaos, algorithms may be able to perform iterative phases of searching faster than typical stochastic search with standard probability distributions [12]. To get there, one-dimensional chaos maps are used to create a collection of new chaos-based gorilla troop optimizer (CBGTO) variants. For this work, ten such chaotic maps are used.

The parent technique's two regulating parameters, namely P and W, are used for chaotic variation. Furthermore, five random variables (R_1-R_5) are simultaneously adjusted in different combination with the two previously described regulating factors to develop 50 different as well as new chaos-based approaches. Actually, R_1-R_3 aid in the GTO method's exploration phase, whereas R_4-R_5 aid in the exploitation step. Both of these processes are improved in the resulting algorithms. Table 1 lists the acronyms for the various algorithms proposed in this work.

The created algorithms are then tested to model a higher-order induction motor. Using the proposed CBGTO approaches, the 5th order system is reduced to a second order model using the concept of delta transform theory. At high sampling time, the delta-transformed model reproduces its continuous-time equivalent. A set of new algorithms are also employed to assess the efficacy of the proposed technique. In addition, an intelligent PID controller is developed in this study using the aforementioned method and an approximate model matching topology. To compare the controlled plant model with unknown controller parameters, a reference model with some desired criteria is chosen. The convergence curves are generated in both the model reduction and controller design parts to demonstrate the fact that the CBGTO approaches outperform several common metaheuristic techniques in terms of speed and accuracy.

Model simulation and its analysis:

A 50 hp induction motor is used in the study to test the validity of the proposedtechnique [13]. The mathematical model of this motor is shown as

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$$G(s) = \frac{2085s^3 + 511000s^2 + 3.081e07\,s + 4.676e09}{s^5 + 397.9s^4 + 184800s^3 + 4.151e07s^2 + 3.408e09\,s + 4.076e10} \quad (1)$$

The delta transformed system is normally written in the γ-domain. Thus, the delta operator based test model is represented by Eqn. (2) corresponding to a sampling time of 0.0025 secs.

$$G(\gamma) = \frac{2.131\gamma^4 + 2084.7\gamma^3 + 3.887e05\gamma^2 + 3.179e07\gamma + 2.71e09}{\gamma^5 + 609.98\gamma^4 + 2.17e05\gamma^3 + 3.454e07\gamma^2 + 2.125e9\gamma + 2.362e10} \quad (2)$$

It is clear that the model is of order five.

Table 1. Acronyms of the various CBGTO methods

Nomenclature of algorithm	Variation in the algorithm	Chaotic map used
CBGTO-1	P, W, R_1, R_2, R_3	Chebyshev Map
CBGTO-2	P, W, R_1, R_2, R_3	Circle Map
CBGTO-3	P, W, R_1, R_2, R_3	Gauss Map
CBGTO-4	P, W, R_1, R_2, R_3	Iterative Map
CBGTO-5	P, W, R_1, R_2, R_3	Logistic Map
CBGTO-6	P, W, R_1, R_2, R_3	Piece wise Map
CBGTO-7	P, W, R_1, R_2, R_3	Sine Map
CBGTO-8	P, W, R_1, R_2, R_3	Singer Map
CBGTO-9	P, W, R_1, R_2, R_3	Sinusoidal Map
CBGTO-10	P, W, R_1, R_2, R_3	Tent Map
CBGTO-11	P, W, R_2, R_3, R_4	Chebyshev Map
CBGTO-12	P, W, R_2, R_3, R_4	Circle Map
CBGTO-13	P, W, R_2, R_3, R_4	Gauss Map
CBGTO-14	P, W, R_2, R_3, R_4	Iterative Map
CBGTO-15	P, W, R_2, R_3, R_4	Logistic Map
CBGTO-16	P, W, R_2, R_3, R_4	Piece wise Map
CBGTO-17	P, W, R_2, R_3, R_4	Sine Map
CBGTO-18	P, W, R_2, R_3, R_4	Singer Map
CBGTO-19	P, W, R_2, R_3, R_4	Sinusoidal Map
CBGTO-20	P, W, R_2, R_3, R_4	Tent Map
CBGTO-21	P, W, R_3, R_4, R_5	Chebyshev Map
CBGTO-22	P, W, R_3, R_4, R_5	Circle Map
CBGTO-23	P, W, R_3, R_4, R_5	Gauss Map
CBGTO-24	P, W, R_3, R_4, R_5	Iterative Map
CBGTO-25	P, W, R_3, R_4, R_5	Logistic Map
CBGTO-26	P, W, R_3, R_4, R_5	Piece wise Map
CBGTO-27	P, W, R_3, R_4, R_5	Sine Map
CBGTO-28	P, W, R_3, R_4, R_5	Singer Map
CBGTO-29	P, W, R_3, R_4, R_5	Sinusoidal Map
CBGTO-30	P, W, R_3, R_4, R_5	Tent Map

CBGTO-31	P, W, R_4, R_5, R_1	Chebyshev Map
CBGTO-32	P, W, R_4, R_5, R_1	Circle Map
CBGTO-33	P, W, R_4, R_5, R_1	Gauss Map
CBGTO-34	P, W, R_4, R_5, R_1	Iterative Map
CBGTO-35	P, W, R_4, R_5, R_1	Logistic Map
CBGTO-36	P, W, R_4, R_5, R_1	Piece wise Map
CBGTO-37	P, W, R_4, R_5, R_1	Sine Map
CBGTO-38	P, W, R_4, R_5, R_1	Singer Map
CBGTO-39	P, W, R_4, R_5, R_1	Sinusoidal Map
CBGTO-40	P, W, R_4, R_5, R_1	Tent Map
CBGTO-41	P, W, R_5, R_1, R_2	Chebyshev Map
CBGTO-42	P, W, R_5, R_1, R_2	Circle Map
CBGTO-43	P, W, R_5, R_1, R_2	Gauss Map
CBGTO-44	P, W, R_5, R_1, R_2	Iterative Map
CBGTO-45	P, W, R_5, R_1, R_2	Logistic Map
CBGTO-46	P, W, R_5, R_1, R_2	Piece wise Map
CBGTO-47	P, W, R_5, R_1, R_2	Sine Map
CBGTO-48	P, W, R_5, R_1, R_2	Singer Map
CBGTO-49	P, W, R_5, R_1, R_2	Sinusoidal Map
CBGTO-50	P, W, R_5, R_1, R_2	Tent Map

It is more difficult to synthesis its controller. As a result, the CBGTO approaches proposed reduce this model to a second-order system. Since just four decision variables are included in this test, 20 search agents and 100 iterations are used. Along with the parent algorithm, many new approaches such as the Arithmetic Optimization Algorithm (AOA), African Vulture Optimization Algorithm (AVOA), Political Optimizer (PO), Slime Mould Algorithm (SMA), and War Strategy Optimization (WSO) [14-18] are employed for comparison. The delta-operator based second order models are developed by reducing Eqn (2) using a constrained optimization based method. It is found that among the proposed techniques the methods CBGTO-01, CBGTO-14, CBGTO-37, and CBGTO-50 produce the least value of average error having magnitude of 0.0104 while the technique CBGTO-26 yields the minimum standard deviation of error (1.36e-12), demonstrating that this algorithm is the most stable of the methods used for comparison. The convergence graphs of some selected proposed approaches are depicted in Figs. 1-3.

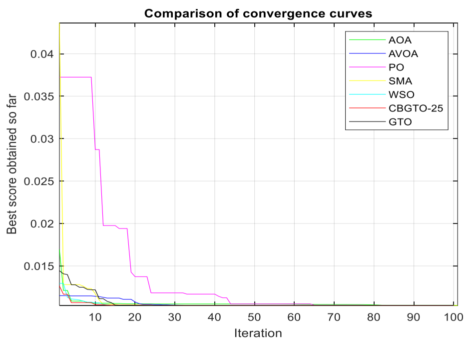

Fig. 1. Convergence curve of CBGTO-25 with respect to other methods

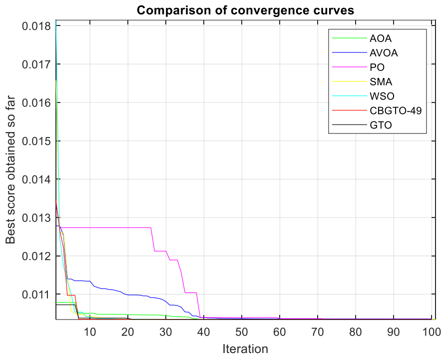

Fig. 2. Convergence characteristic of CBGTO-49 with other methods

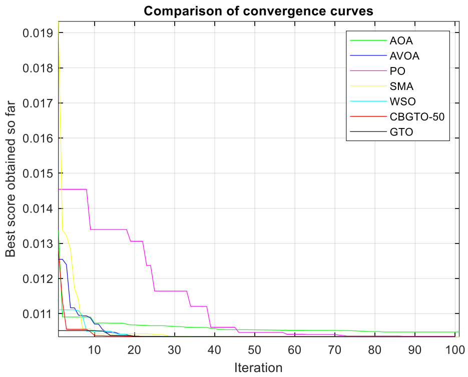

Fig. 3. Convergence curve of CBGTO-50 with other methods

The suggested CBGTO approaches produce not only good convergence accuracy but also significant convergence speed. Figures 1-3 clearly demonstrate this. The transient specifications of the reduced systems are further calculated and compared to the original system, as well as several popular classical techniques and also some of the most recent metaheuristic techniques. The rise time (in seconds), settling time (in seconds), and overshoot (in %) are all measured in the time domain. The gain margin (in dB) and phase margin (in degrees) are calculated in the frequency domain. Table 2 summarizes the findings.

Table 2. Transient specifications of the reduced 50 hp induction motor models

S No.	Algorithms	Rise time (secs)	Settling time (secs)	Overshoot (%)	GM (dB)	PM (degrees)
1	**Original**	0.16582	0.28238	0	Inf	Inf
2	Pade	0.16062	0.28222	0	Inf	Inf
3	Routh	0.15754	0.28152	0	Inf	Inf
4	Routh-Pade	0.15754	0.28152	0	Inf	Inf
5	BT	0.14109	0.26166	0	Inf	Inf

6	HNA	0.37525	0.69058	0	Inf	Inf
7	CBGTO-01	0.17935	0.29194	0.07764	Inf	Inf
8	CBGTO-02	0.08413	0.38566	7.32040	Inf	Inf
9	CBGTO-13	0.17540	0.28186	0.13171	Inf	Inf
10	CBGTO-14	0.17818	0.28667	0.14303	Inf	Inf
11	CBGTO-25	0.17966	0.28444	0.15874	Inf	Inf
12	CBGTO-26	0.16823	0.25946	0.53597	Inf	Inf
13	CBGTO-37	0.18794	0.36598	0.35698	Inf	Inf
14	CBGTO-39	0.14264	0.42766	0	Inf	Inf
15	CBGTO-49	0.14546	0.45652	0.48752	Inf	Inf
16	CBGTO-50	0.15899	0.18465	0.84657	Inf	Inf
17	GTO	0.17186	0.17642	0.48795	Inf	Inf
18	AOA	0.17439	0.13482	0.14786	Inf	Inf
19	AVOA	0.15012	0.63874	4.62695	Inf	Inf
20	PO	0.19015	0.31522	0.33328	Inf	Inf
21	SMA	0.16884	2.63376	4.30600	Inf	Inf
22	WSO	0.14898	0.65055	4.85575	Inf	Inf

It is found from Table 2 that the proposed techniques perform fairly well with respect to time and frequency domain parameters. The comparison is not only carried out with respect to the original system but also with reference to some of the widely accepted classical methods of model reduction. The methods CBGTO-26 and SMA yield the closest rise time, while CBGTO-13, CBGTO-14, and CBGTO-25 produce the closest settling time. The CBGTO-01 and CBGTO-39 report the closest overshoot. Almost all methods reported produce closest gain and phase margins.

Following model reduction, realizable controllers for the reduced systems are created. The reference model technique is used. According to [11], a standard model is used. This is compared with the controlled plant model, which has unknown controller gains. As a result of the approximate model matching (AMM) method, an intelligent PID controller is achieved. To calculate the controller gains, the square error (SE) is used as the objective function. The controller is synthesized in the delta domain. The controller produced by CBGTO-25 is given by

$$G_c(\gamma) = 42.6 + \frac{0.05}{\gamma} + 4.2\gamma \qquad (3)$$

However, the Political Optimizer (PO) algorithm yields the least square error, having a value of 0.016 while the errors produced by the proposed techniques are close to 0.024. Moreover, the outcomes of the methods AVOA, WSO, and the parent GTO method are also close. The distinction can thus be made in terms of the obtained convergence curves. Figs. 4-5 show convergence graphs of few selected methods for the understanding of the readers.

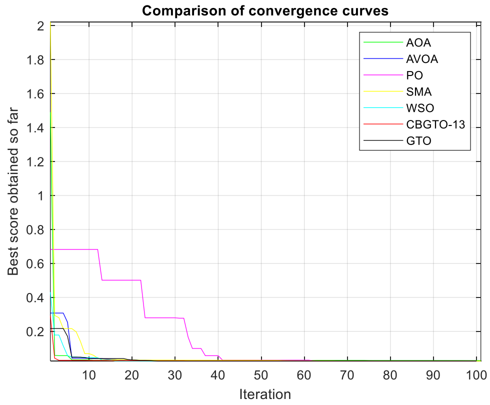

Fig. 4. Convergence curve of CBGTO-13 with other methods

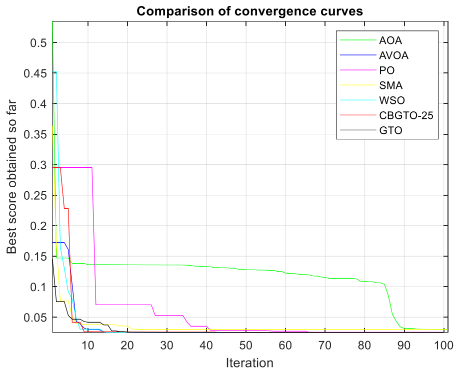

Fig. 5. Convergence characteristic of CBGTO-25 with reference to other methods

The graphs in Figs. 4-5 show that the proposed CBGTO techniques converged faster than the methods compared. The position update rule, as well as the algorithm's random parameters (R_1-R_5), can be changed to generate various different chaotic variations. Different other combinations of random numbers (R_1-R_5) can potentially be studied in the near future.

Conclusions and future directions:

This paper provides a new chaotic development approach for the gorilla troop optimizer. The parent algorithm's 'P' and

'W' parameters can be changed using one-dimensional chaotic maps, but so can some random number generators (R_1-R_5). By chaotically altering R_1, R_2,..., R_5 in five different combinations and both the parameters mentioned above, the yield is considerably increased. The development of these novel chaotic algorithms is being investigated using ten well-known and frequently mentioned chaotic maps. As a result, 50 new algorithms are created, referred CBGTO-01 through CBGTO-50. The proposed approaches are tested using a higher-order induction motor model. According to the delta transform hypothesis, the order of a 50-horsepower induction motor can be reduced. An intelligent controller is realized using an approximate model-matching framework. The new approaches outperform traditional heuristics in terms of speed and accuracy. The results of the trials show a lot of potential. This approach can be used by scientists and engineers to address a wide range of difficult design problems. By modifying the algorithm's location update rule and random parameters, new chaotic algorithms can be developed (R_1-R_5). In the near future, various other combinations of random numbers (R_1-R_5) may be examined in a variety of methods.

References

1. Bocker, J., & Mathapati, S. (2007). State of the art of induction motor control. In 2007 IEEE International Electric Machines & Drives Conference (Vol. 2, pp. 1459-1464).

2. Yang, H., Xia, Y., & Geng, Q. (2019). Analysis and synthesis of delta operator systems with actuator saturation (Vol. 193). Singapore: Springer.

3. Ganguli, S., Kaur, G., Sarkar, P., & Rajest, S. S. (2020). An Algorithmic Approach to System Identification in the Delta Domain Using FAdFPA Algorithm. In Business Intelligence for Enterprise Internet of Things (pp. 203-211). Springer, Cham.

4. Ganguli, S., Srivastava, T., Kaur, G., & Sarkar, P. (2022). Model Reduction and Controller Scheme Development of Permanent Magnet Synchronous Motor Drives in the Delta Domain Using a Hybrid Firefly Technique. Handbook of Intelligent Computing and Optimization for Sustainable Development, 537-547.

5. Ganguli, S., Kaur, G., & Sarkar, P. (2019). Identification in the delta domain: a unified approach using hybrid FAPS algorithm. In 2019 5th International Conference on Advanced Computing & Communication Systems (ICACCS) (pp. 1093-1096).

6. Ganguli, S., Kaur, G., & Sarkar, P. (2021). Global heuristic methods for reduced-order modelling of fractional-order systems in the delta domain: a unified approach. Ricerche di Matematica, 1-29.

7. Gharehchopogh, F. S., Maleki, I., & Dizaji, Z. A. (2021). Chaotic vortex search algorithm: metaheuristic algorithm for feature selection. Evolutionary Intelligence, 1-32.

8. Pierezan, J., dos Santos Coelho, L., Mariani, V. C., de Vasconcelos Segundo, E. H., & Prayogo, D. (2021). Chaotic coyote algorithm applied to truss optimization problems. Computers & Structures, 242, 106353.

9.Abdollahzadeh, B., Soleimanian Gharehchopogh, F., & Mirjalili, S. (2021). Artificial gorilla troops optimizer: a new nature-inspired metaheuristic algorithm for global optimization problems. International Journal of Intelligent Systems, 36(10), 5887-5958.

10. Middleton, R., & Goodwin, G. C. (1986). Improved finite word length characteristics in digital control using delta operators. IEEE transactions on automatic control, 31(11), 1015-1021.

11. Ganguli, S., Kaur, G., & Sarkar, P. (2022). An approximate model matching technique for controller design of linear time-invariant systems using hybrid firefly-based algorithms. ISA transactions, 127, 437-448.

12. Ahmed, S., Mafarja, M., Faris, H., & Aljarah, I. (2018). Feature selection using salp swarm algorithm with chaos. In Proceedings of the 2nd international conference on intelligent systems, metaheuristics & swarm intelligence (pp. 65-69).

13. Wasynezuk, O., Diao, Y. M., & Krause, P. C. (1985). Theory and comparison of reduced order models of induction machines. IEEE transactions on power apparatus and systems, (3), 598-606.

14. Abualigah, L., Diabat, A., Mirjalili, S., Abd Elaziz, M., & Gandomi, A. H. (2021). The arithmetic optimization algorithm. Computer methods in applied mechanics and engineering, 376, 113609.

15. Abdollahzadeh, B., Gharehchopogh, F. S., & Mirjalili, S. (2021). African vultures optimization algorithm: A new nature-inspired metaheuristic algorithm for global optimization problems. Computers & Industrial Engineering, 158, 107408.

16. Li, S., Chen, H., Wang, M., Heidari, A. A., & Mirjalili, S. (2020). Slime mould algorithm: A new method for stochastic optimization. Future Generation Computer Systems, 111, 300-323.

17. Ayyarao, T. S., RamaKrishna, N. S. S., Elavarasan, R. M., Polumahanthi, N., Rambabu, M., Saini, G., ... & Alatas, B. (2022). War strategy optimization algorithm: a new effective metaheuristic algorithm for global optimization. IEEE Access, 10, 25073-25105.

18. Askari, Q., Younas, I., & Saeed, M. (2020). Political Optimizer: A novel socio-inspired meta-heuristic for global optimization. Knowledge-based systems, 195, 105709.