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A Decade Review Of The Engineering Applications Of The Modified Firefly Algorithm (2013 - 2022)

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Abstract:
The engineering applications of the modified Firefly Algorithm (FA) have shown promise in various fields due to its optimization capabilities. Over the years, modifications and adaptations have been made to improve its efficiency and application in engineering coverings areas such as; Structural Engineering, Mechanical Engineering, Electrical Engineering, Renewable Energy, Robotics and Automation, Communication Networks, Water Resources and Environmental Engineering, Software and Artificial Intelligence. This work will perform an empirical and comparative review of the various engineering application jobs done by researchers using the modified firefly algorithm from 2013 to 2022. A study of about 145 works done by researchers in different areas of Innovation, Science and Technology was performed, 50 of these were chosen and further analyzed for the purpose of this work. An empirical and comparative analysis, done in this decade review 2013 -2022, has shown that the Modified Firefly Algorithm has constantly been in the front burner and has proven to be a veritable tool in solving various optimization problems in science and engineering.

Keywords: *Metaheuristic; firefly algorithm; convergence; global optima; optimization.*

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I. Introduction:

The Firefly Algorithm is inspired by the flashing behavior of fireflies and is utilized to solve optimization problems. The primary difference between the Firefly Algorithm and its modified versions lies in the enhancements, adjustments, or adaptations made to the original algorithm. The modifications aim to overcome the limitations and improve the algorithm's efficiency, convergence, and robustness in solving optimization problems across various domains.

Firefly Algorithm

Yang, Xin-She in 2008 first developed the firefly algorithm (FA) as part of his research into swarm based intelligent algorithms. Specifically, They, looked at the natural behavior of the tropical firefly, with the goal to create an algorithm that mimics the flashing light pattern and mating/attraction behavior of the biological firefly. The purpose of the flashing lights is two folds: to attract mating partners and to ward off potential predators (Ali *et al*., 2014).

In constructing the optimization problem which uses FA, certain fundamental requirements have to be met. These requirements which might be problem dependent, leverage the unique properties of a biologically inspired metaheuristic algorithm like the FA to obtain a global best solution (Yang & He, 2013). Some of the problem dependent properties talked about include nonlinearity, coupled functions, non-convexity of model, NP-hardness etc.

Although, without having a detailed full proof mathematical treatment of most metaheuristic techniques, FA like the other metaheuristic counterparts, have been known to work very well, even surpassing the more structured well known deterministic or exact optimization solution examples like Branch and bound, simplex method and gradient descent method are good examples of exact solution methods and which most times yield only local best solutions(Ali *et al*., 2014; Khan, *et al*., 2016).

How the FA works

Two main research directions or branches have evolved out of the original FA. These are the modified and the hybrid branch. These two branches summarize all the different variants of the FA (Fister *et al*., 2013). In

the treatment that follows, the detailed look at the original FA by Yang in 2008, will be well established before mention is made of the other modified versions.

Fister *et al*., (2014) summarized the assumptions which were made about the Firefly before development of the algorithm to include:

a. All fireflies are unisex, so that one firefly will be attracted to other fireflies regardless of their sex.
b. The attractiveness is proportional to the brightness and they both decrease as their distance increases. Thus, for any two flashing fireflies, the "less bright" one will move towards the brighter one. If there is no brighter one than a particular firefly, it will move randomly.
c. The brightness of a firefly is determined by the landscape of the objective function.

To begin the algorithm development, the brightness or variation of light intensity of the firefly which is the main defining characteristics of the FA is explained by the attractiveness factor represented by beta. The twin issues of light intensity (brightness) and attractiveness, help developers to tailor different FAs to their specific problems (Fister *et al*., 2013). Yang's 2008 FA describes the light intensity of a firefly '***I***' representing the solution '***s***' is proportional to the value of the fitness function with the light intensity varying according to the relation

$$I(s) \propto f(s)$$

$$I(r) = I_0 e^{-\gamma r^2} \quad 1.1$$

where I_0 denotes the light intensity of the source, and the light absorption is approximated using the fixed light absorption coefficient γ. The singularity at $r = 0$ in the expression I/r^2 is avoided by combining the effects of the inverse square law and an approximation of absorption in Gaussian form (Fister *et al*., 2013).

This attractiveness is proportional to the light intensity seen by other fireflies and can allow the definition of the variation of brightness with distance r (similar to what has been done with the light intensity) as

$$\beta = \beta_0 e^{-\gamma r^2} \quad 1.2$$

Where β_0 is the attractiveness at r=0 (Fister *et al*., 2014). The light intensity and attractiveness β are in some way synonymous. Whilst the intensity is referred to as an absolute measure of emitted light by the firefly, the attractiveness is a relative measure of the light that should be seen in the eyes of the beholders and judged by other fireflies (Yang, 2008; Fister et al., 2013)

To define the movement of firefly "***i***" towards firefly "***j***", the distance between the two fireflies is first given by the standard Euclidean distance. The distance between any two fireflies x_i and x_j is expressed by the base firefly algorithm, as:

$$r_{ij} = \| x_i - x_j \| = \sqrt{\sum_{k=1}^{k=n} (x_{ik} - x_{jk})^2} \quad 1.3$$

With n denoting the dimensionality of the problem. The movement of a firefly "***i***" is attracted to another brighter firefly "***j***" by the function

$$x_i^{t+1} = x_i^t + \beta_0 e^{-\gamma r_{ij}^2} (x_j^t - x_i^t) + \alpha \varepsilon_i^t \quad 1.4$$

Where the second term captures the attraction between fireflies and the third term is a randomization term used to vary the search space to avoid the local minima problem. $\underline{\varepsilon_i^t}$ is a vector of random numbers drawn from a Gaussian distribution at time t or any other acceptable random number generator with uniform distribution such as Levy Flight. The gamma term controls the scaling while alpha controls the randomness. For the algorithm to converge properly, the randomness should be gradually reduced with a candidate reduction function being

$$\alpha = \alpha_0 \theta(t) \quad 1.5$$

where $\theta \in (0,1)$

Where t is the index of iterations/generations, α_0 is the initial randomness factor which allows a value **0(1)** without a loss of generality. The FA can now be presented as in Algorithm of the Standard FA (Khan et al., 2016), as given below:

Set algorithm parameters (α, γ)

Set simulation set-up (Number of initial solutions and maximum iteration (N,MaxGen))

Randomly generate N initial solutions
for iteration = 1:MaxGen
Compute the brightness, I
Sort the solution in such a way that, $I_i \geq I_{i-1} \forall i$
for i=1:n-1
for j=i+1:n
if $I_j > I_i$
move firefly i towards firefly j
end if
end for
end for

move firefly N, (X_b **), randomly end for Select the best solution**

In summary, it has been shown that the movements of fireflies consist of three terms: the current position of ***i***-th firefly, attraction to another more attractive firefly, and a random walk that consists of a randomization parameter α and the random generated number from interval [0, 1]. When $\boldsymbol{\beta_0} = 0$ the movement depends on the random walk only. On the other hand, the parameter γ has a crucial impact on the convergence speed. Although the value of this parameter can theoretically capture any value from interval $\boldsymbol{\gamma \in [0,} \infty)$, its setting depends on the problem to be optimized. Typically, it varies from 0.1 to 10 (Fister *et al*., 2013).

The FA is also controlled by three parameters: the randomization parameter $\boldsymbol{\alpha}$, the attractiveness β, and the absorption coefficient γ. According to the parameter setting, FA distinguishes two asymptotic behaviours. The former appears when $\boldsymbol{\gamma} \rightarrow 0$ and the latter when $\boldsymbol{\gamma} \rightarrow \infty$. If $\boldsymbol{\gamma} \rightarrow 0$, the attractiveness becomes $\boldsymbol{\beta} = \boldsymbol{\beta_0}$. That is, the attractiveness is constant anywhere within the search space.

Variants of the Firefly Algorithm

The two main branches of the FA exist by way of different directions to which FA research has proceeded over time. These are the modified FA branch and the Hybrid FA branch. Table 1.1 summarizes these two branches (Fister *et al.*, 2014)

Table 1.1: Variants of the Firefly Algorithm

S/N	Modified FA	Hybrid FA
1	Elitist	Eagle strategy
2	Binary	Genetic algorithm
3	Gaussian	Differential evolution
4	Levy flights	Memetic algorithm
5	Chaos	Neural network
6	Parallel	Cellular learning automata
7	Multi-population	Ant colony
8	Harmonic clustering	Simulated annealing
9		Evolutionary strategies

Modified Firefly Algorithm (MFA)

The MFA was used as an easy implementation technique allowing the bio-inspired FA algorithms to search for the optimal point in the opposite direction of the last search. The basic idea of this technique is that when performing a local search in one direction, it is important to also consider what lies in the opposite direction. In this way and unlike ordinary FA, the MFA approach allows us to improve the quality of the solution and preserve the diversity of the swarm. The MFA method is based on the concept of the opposite number, defined by Equation (1.6)

$$\breve{x} = a + b\ X\ x \qquad 1.6$$

Where x is an actual number defined in the range [a; b] and $\breve{x}$ is the opposite number of x. which is valid for N-dimensional points x_1 defined in the range $[a_i; b_i]$, i = 1; 2;…..; N.

The MFA is implemented using the flowchart shown below

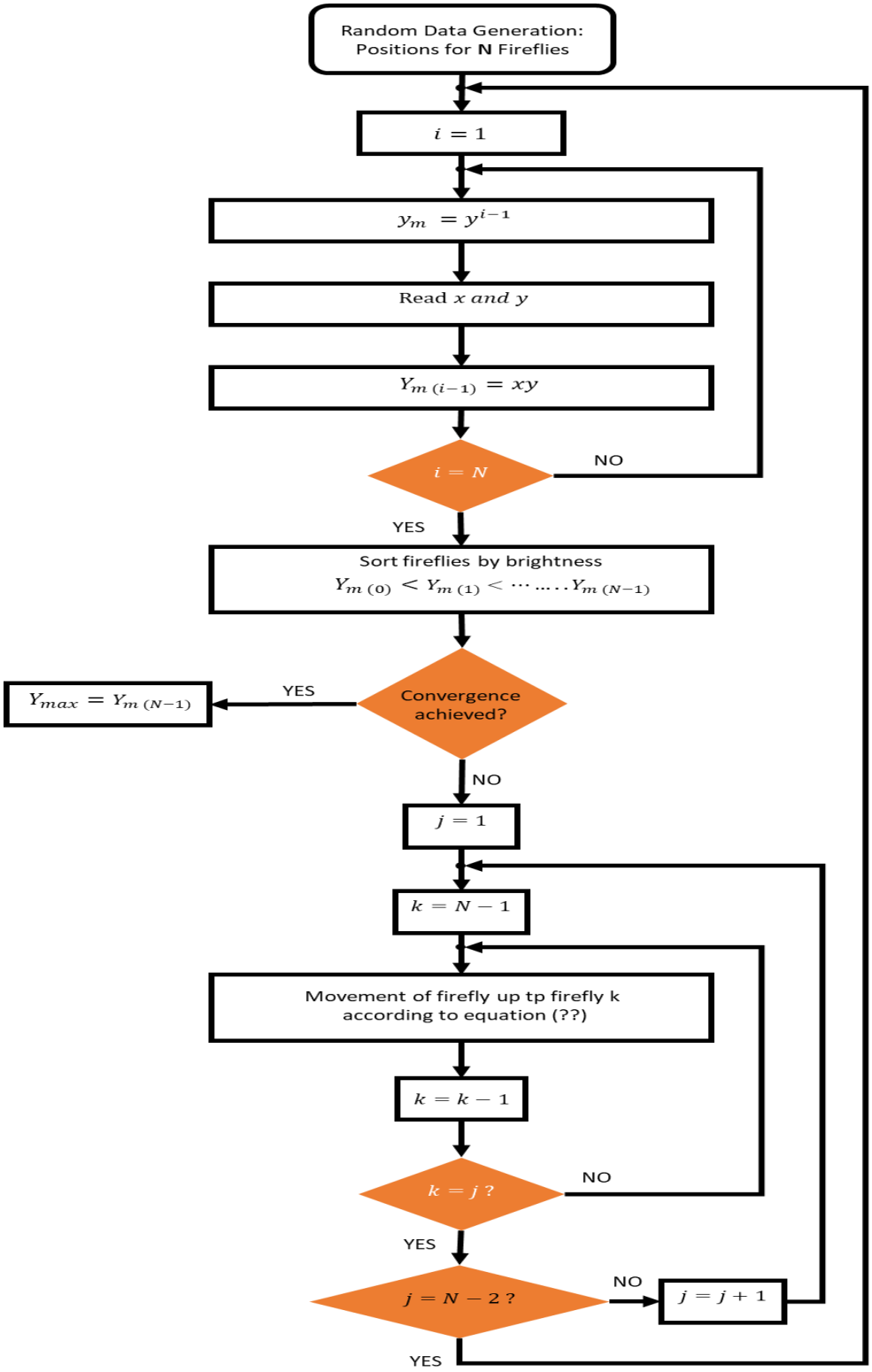

Figure 1.1: Flowchart for Optimal Trajectory tracking using Modified firefly Algorithm.

In the ordinary firefly algorithm, there is no step to calculate the comparative individual aptitude values. Therefore, the particles do not return to their original position when no benefits result from their first move, always then moving again towards their closest best neighbor. To overcome this drawback, the modified method allows FA to search for the optimal point in the opposite direction of the current search. Figure 1.1 shows the flowchart for the modified firefly optimization method, where y and x are the measured distances, Y is the maximum objective function between the firefly pair.

II. Materials and Method:

/ N	SOURCE	AUTHOR(S)	TITLE	WORK DONE	IMPROVEMENT
	Elsevier Journal of Swarm and Evolutionary Computation Vol13. December 2013, Pages 34-46 https://doi.org/10.1016/j.swevo.2013.06.001	Iztok Fister, Iztok Fister Jr., Xin-She Yang , Janez Brest.	A comprehensive review of firefly algorithms	A comprehensive review of the firefly algorithm.	Shown that FA possesses multi-modal characteristics, can handle multi-modal problems efficiently, has a fast convergence rate.
	Elsevier Journal of Expert Systems with Applications Vol 40, Issue 18, 15 December 2013, Pages 7220-7230. https://doi.org/10.1016/j.eswa.2013.06.070	Iztok Fister, Iztok Fister Jr., Xin-She Yang , Janez Brest.	Modified firefly algorithm using quaternion representation.	A novel representation of individuals with quaternions in the quaternion firefly algorithm. QFA	The proposed firefly algorithms using quaternion's representation improved the results of the original firefly algorithm
	Pages 47-65 | Published online: 30 Jan 2014 https://doi.org/10.1080/08839514.2014.862773	Tahereh Hassanzadeh, Hamidreza Rashidy Kanan.	Fuzzy FA: A Modified Firefly Algorithm	A fuzzy-based, modified version of the standard FA—the fuzzy firefly algorithm (FFA).	Effective to find the global optima and can improve the global search and the exploration rate of the standard FA.
	Elsevier Journal of Advances in Engineering Software Vol. 81. Issue C March 2015. pp 50–65. https://doi.org/10.1016/j.advengsoft.2014.11.003	Saeed Gholizadeh.	Performance-based optimum seismic design of steel structures by a modified firefly algorithm and a new neural network.	Modified firefly algorithm (MFA) is proposed to efficiently find performance-based optimum seismic design PBOSD.	A new MFA meta-heuristic is proposed for achieving optimization task by hybridizing meta-heuristic optimization algorithms and neural networks.
	2014 8th. Malaysian Software Engineering Conference (MySEC) DOI: 10.1109/MySec.2014.6986037	Ali Safari Mamaghani, Meysam Hajizadeh.	Software modularization using the modified firefly algorithm	Software modularization to increase the maintenance of software systems.	Experimental results reveal that in most of the cases the proposed approach has a remarkable superiority over both the Genetic and the Learning Automaton algorithms in solving the problem.
	PLOS ONE | www.plosone.org November 14, 2014 https://doi.org/10.1371/journal.pone.0112634	Ngaam J. Cheung , Xue-Ming Ding , Hong-Bin Shen.	Adaptive Firefly Algorithm: Parameter Analysis and its Application	Investigated the parameter selection and adaptation strategies in a modified firefly algorithm	Adaptive firefly algorithm (AdaFa). Numerical experiments and statistical tests yield useful conclusions on the strategies and the parameter selections affecting the performance of AdaFa.
	International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014). DOI**:** 10.1109/ICRAIE.2014.6909251	Divya Gupta, Medha Gupta.	Evaluation of a new modified Firefly algorithm	Modified Firefly Algorithm (MOFA). Emergent behavior successful in bridging the gap from idealistic situation to reality.	Performance of modified version of Firefly algorithm (MoFA) was compared with standard FA and two more versions of FA on various parameters. MOFA was superior to all the other three algorithms in all aspects.
	Elsevier Journal of Expert Systems with Applications. Vol. 41, Issue 13, 1 October 2014, Pages 6047-6056 https://doi.org/10.1016/j.eswa.2014.03.053.	Abdollah Kavousi-Fard, Haidar Samet, Fatemeh Marzbani.	A new hybrid Modified Firefly Algorithm and Support Vector Regression model for accurate Short Term Load Forecasting.	A hybrid prediction algorithm that was comprised of Support Vector Regression (SVR) and Modified Firefly Algorithm (MFA)	A novel hybrid technique based on SVR to provide a more accurate and stable model for short term electrical load forecast.
	Indian Journal of Science and Technology, Vol. 8(23), September 2015. DOI: 10.17485/ijst/2015/v8i23/72264.	S. Meena1, K. Chitra.	Modified Approach of Firefly Algorithm for Non-Minimum Phase Systems	A modified approach of firefly algorithm is compared with the firefly algorithm. Derived from the impact of the tuning	A novel way of obtaining PID tuned parameters for any second order system with a modified approach using firefly algorithm.

				parameters over the objective function peak overshoot.	
0	Elsevier Journal of Journal of Magnetism and Magnetic Materials Vol. 395, 1 December 2015, Pages 229-233 https://doi.org/10.1016/j.jmmm.2015.07.080.	Mohammad Asif Zaman, Urmita Sikder.	Bouc–Wen hysteresis model identification using Modified Firefly Algorithm.	Algorithm uses dynamic process control parameters to improve the performance of the parameters of Bouc–Wen hysteresis Model.	Compared with Firefly Algorithm, Genetic Algorithm and Differential Evolution algorithm in terms of convergence rate and accuracy the algorithm is found to have good convergence rate with high degree of accuracy in identifying Bouc–Wen model parameters.
1	Elsevier Journal of Expert Systems with Applications https://doi.org/10.1016/j.eswa.2015.08.054	Om Prakash Verma, Deepti Aggarwal, Tejna Patodi.	Opposition and dimensional based modified firefly algorithm	Opposition-based methodology where initialization of candidate solutions is done using opposition based learning to improve convergence rate of original FA,	The rate of convergence is faster and time complexity reduced by opposition-based Firefly Algorithm.
2	International Journal on Electrical Engineering and Informatics Vol. 7, Number 4, December 2015.	Anang Tjahjono, Dimas Okky Anggriawan, Alfa Kusnal Faizin, Ardyono Priyadi, Margo Pujiantara, Mauridhi Hery Purnomo.	Optimal Coordination of Overcurrent Relays in Radial System with Distributed Generation Using Modified Firefly Algorithm	An optimal Overcurrent relay (OCR) coordination in radial system under the presence of distributed generation (DG).	Method can significantly improve the result of the FA and reduce all cases operating time of the OCR coordination, which reaches 38.38 %.
3	Pertanika J. Sci. & Technol. 23 (2): 251 - 269 (2015).	Hong Choon Ong, Surafel Luleseged Tilahun, Suey Shya Tang.	A Comparative Study on Standard, Modified and Chaotic Firefly Algorithms.	Compared the Standard Firefly Algorithm, the Modified Firefly Algorithm with the Chaotic Firefly Algorithm, which embeds chaos maps in the Standard Firefly Algorithm.	Modified Firefly Algorithm outperformed the other versions in average performance and also had a smaller standard deviation.
4	Hindawi Publishing Corporation Mathematical Problems in Engineering Vol. 2015, Article ID 561394, 10 pages http://dx.doi.org/10.1155/2015/561394	Chang Liu, Yuxin Zhao, Feng Gao, Liqiang Liu.	Three-Dimensional Path Planning Method for Autonomous Underwater Vehicle Based on Modified Firefly Algorithm.	The optimization the complexity of three-dimensional (3D) path planning for autonomous underwater vehicles (AUVs) using Modified Firefly Algorithm.	The modified FA has a quick convergence speed and the path planning method based on it can find an effective path in a 3D environment.
5	Periodica Polytechnica Electrical Engineering and Computer Science, 59(3), pp. 104–109, 2015. https://doi.org/10.3311/PPee.8579.	Othman M. M, Hegazy Y. G, Abdelaziz A. Y.	A Modified Firefly Algorithm for Optimal Sizing and Siting of Voltage Controlled Distributed Generators in Distribution Networks	Method modifies the traditional FA method via proposing formulas for the FA parameters and updating equations.	The modified FA method determines accurately the optimal location, capacity of voltage-controlled DG in order to minimize the system power loss.
6	Journal of Water Resources Planning and Management Vol. 142, Issue 9 (2016). https://doi.org/10.1061/(ASCE)WR.1943-5452.0000644.	Irene Garousi-Nejad, Omid Bozorg-Haddad, Hugo A. Loáiciga.	Modified Firefly Algorithm for Solving Multi-reservoir Operation in Continuous and Discrete Domains.	A modified firefly algorithm (MFA) and applies it to optimally solve reservoir operation problems for water resources management.	MFA results were better than linear programming (LP), differential dynamic programming (DDP), and discrete DDP (DDDP), the genetic algorithm (GA), the multi-colony ant algorithm (MCAA), the honey-bee mating optimization (HBMO) algorithm, the water cycle algorithm (WCA), the bat algorithm (BA), and the

					biogeography-based optimization (BBO) algorithm.
7	The International Journal of Advanced Manufacturing Technology. Vol. 82, pages1381–1403 (2016).	Mingfu Li, Yuyan Zhang, Bing Zeng, Houming Zhou, Jingang Liu.	The modified firefly algorithm considering fireflies' visual range and its application in assembly sequences planning.	A modified discrete firefly algorithm (MDFA) to solve the problem of assembly sequence planning.	MDFA endowed the fireflies with the capability of changeable visual range hence making it more effective and robust than standard FA, genetic algorithm and particle swarm optimization algorithm.
8	IEEE Journal of Emerging and Selected Topics in Power Electronics DOI: 10.1109/ JESTPE.2016.2581858.	D. F. Teshome, C. H. Lee, Y. W. Lin, K. L. Lian.	A Modified Firefly Algorithm for Photovoltaic Maximum Power Point Tracking Control Under Partial Shading.	Maximum power point tracking (MPPT) control algorithms developed to counteract the partial shading conditions (PSC) effects.	Method can track the global point under various PSC, has a faster convergence time compared with the FA, and can effectively suppress power and voltage fluctuations.
9	International Journal of Innovative Studies in Sciences and Engineering Technology (IJISSET) ISSN 2455-4863 (Online) www.ijisset.org Vol. 2. 11 November 2016.	C.Hemalatha, M.Valan Rajkumar, G.Vidhya Krishnan.	Simulation and Analysis of MPPT Control with Modified Firefly Algorithm for Photovoltaic System.	Maximum power tracking methods based on MFA to track the MPP implemented on a boost DC-DC converter.	Method can accurately track the MPP and improve the performance of firefly algorithm (FA) in tracking speed for convergence.
0	2016 IEEE Congress on Evolutionary Computation (CEC) DOI: 10.1109/CEC.2016.77 44067.	Li-Na Zhang, Li-Qiang Liu, Gan-Nan Yuan, Yun-Tao Dai.	Modified firefly algorithm using randomized mechanisms.	Extensive comparison between eight different probability distributions for randomizing the firefly algorithm's attractive mechanism, e.g., Uniform, Gaussian, Exponential, Cauchy Distributions.	results of these experiments show that these randomized mechanisms can improve the convergence rate and the robustness of the firefly algorithm significantly.
1	Elsevier Journal of Applied Energy Vol. 167, 1 April 2016, Pages 135-153 https://doi.org/10.1016/j.ape nergy.2016.01.050.	Liye Xiao, Wei Shao, Tulu Liang, Chen Wang.	A combined model based on multiple seasonal patterns and modified firefly algorithm for electrical load forecasting.	Optimization algorithm is presented and applied to optimize the weight coefficients of the combined model based on non-positive constraint combination theory.	More accurate forecasting for reduced costs and risks, improved the security of power systems and helped administrators develop an optimal action program, thereby enhancing the economic social benefits of power-grid management.
2	Spriinger Journal of Structural and Multidisciplinary Optimization Vol. 55, pages 2013–2028 (2017).	Jui-Sheng Chou, Ngoc-Tri Ngo.	Modified firefly algorithm for multidimensional optimization in structural design problems.	Incorporates metaheuristic components, namely logistic and Gauss/mouse chaotic maps, adaptive inertia weight, and Lévy flight with a conventional firefly algorithm (FA) to improve its optimization capability.	The efficacy of the MFA was then proven by its solutions to three multidimensional structural design optimization problems; MFA yielded the best solutions among the observed algorithms.
3	KSCE Journal of Civil Engineering Vol. 21, pages 535–545 (2017).	Surafel Luleseged Tilahun, Jean Medard T. Ngnotchouye.	Firefly algorithm for discrete optimization problems: A survey.	Detailed review of the modifications done on firefly algorithm in order to solve optimization problems with discrete variables.	Discussed the advances on the application of firefly algorithm for optimization problems with binary, integer as well as mixed variables.
4	Science Direct Journal of Applied Soft Computing Vol. 62, January 2018, Pages 29-44.	Aref Yelghi, Cemal Köse	A modified firefly algorithm for global minimum optimization.	Brought a new strategy using exploitation (Tidal Force) and keeping a balance between the exploration and	The study findings indicate that the Tidal Force Firefly algorithm outperforms the other existing modified Firefly algorithms.

				exploitation on function suitability.	
5	Elsevier Journal of Construction and Building Materials Vol. 180, 20 August 2018, Pages 320-333. https://doi.org/10.1016/j.conbuildmat.2018.05.201.	Dac-Khuong Bui, Tuan Nguyen, Jui-Sheng Chou, H. Nguyen-Xuan, Tuan Duc Ngo.	A modified firefly algorithm-artificial neural network expert system for predicting compressive and tensile strength of high-performance concrete.	To develop an expert system based on the artificial neural network (ANN) model in association with a modified firefly algorithm (MFA).	The result indicates that the MFA-ANN hybrid system can obtain a better prediction of the high-performance concrete properties. The MFA-ANN is also much faster at solving problems.
6	Journal of Computer and Information Science; Vol. 11, No. 1; 2018 ISSN 1913-8989 E-ISSN 1913-8997.	Mahdi Bidar, Samira Sadaoui, Malek Mouhoub, Mohsen Bidar.	Enhanced Firefly Algorithm Using Fuzzy Parameter Tuner.	Introduced an entire fuzzy system to tune efficiently and dynamically the firefly algorithm parameters in order to keep the exploration and exploitation in balance in each of the searching steps.	The experimental results demonstrate the superiority of the fuzzy-based firefly algorithm to standard firefly and also its comparability to other metaheuristic algorithms.
7	Springer Journal of Technology and Economics of Smart Grids and Sustainable Energy Vol. 3, Article number: 9 (2018). https://doi.org/10.1007/s40866-018-0048-7.	Javad Farzaneh, Reza Keypour, Mojtaba Ahmadieh Khanesar.	A New Maximum Power Point Tracking Based on Modified Firefly Algorithm for PV System Under Partial Shading Conditions.	A modified firefly algorithm (MFA) is used and investigated with the objective of Photovoltaic (PV) system Maximum Power Point (MPP) tracking under partial shading conditions (PSCs).	Results show that under PSCs performances of the proposed method, PSO and FA methods in tracking the global MPP are very satisfactory. Also, the proposed method has a higher tracking speed than FA and PSO methods under partial shading conditions. Average efficiency of the proposed method is higher than 99.98%.
8	TELKOMNIKA, Vol.16, No.5, October 2018, pp.2436~2443. DOI: 10.12928/TELKOMNIKA.v16i5.10545.	Nguyen Trung Thang, Nguyen Duy Phuong, Pham Van Thanh, Chiem Trong Hien.	An Effectively Modified Firefly Algorithm for Economic Load Dispatch Problem.	An effectively modified firefly algorithm (EMFA) for searching optimal solution of economic load dispatch (ELD) problem.	The proposed method is much better than FA in terms of finding higher quality solution, using lower population and lower maximum iteration. It also can obtain better quality solution with faster convergence speed.
9	Hindawi Journal of Complexity Vol. 2018, Article ID 7267593, 23 pages https://doi.org/10.1155/2018/7267593.	Thang Trung Nguyen, Nguyen Vu Quynh, Le Van Dai.	Improved Firefly Algorithm: A Novel Method for Optimal Operation of Thermal Generating Units.	A novel improved firefly algorithm (IFA) to deal the problem of the optimal operation of thermal generating units (OOTGU) with the purpose of reducing the total electricity generation fuel cost.	The obtained results indicate the proposed improvements in terms of high optimal solution quality, stabilization of search ability, and fast convergence compared with FA.
0	Elsevier Journal of Applied Soft Computing Vol 68, July 2018, Pages 322-342 https://doi.org/10.1016/j.asoc.2018.04.006.	Gonggui Chen, Xingting Yi, Zhizhong Zhang, Huiming Wang.	Applications of multi-objective dimension-based firefly algorithm to optimize the power losses, emission, and cost in power systems.	A new multi-objective dimension-based firefly algorithm (MODFA) is proposed for solving the constrained multi-objective optimal power flow (MOOPF) problem with multiple and contradictory objectives in power systems.	The numerous simulation results optimized by the MODFA, which are compared with frequently-used NSGA-III, NSGA-II, and MOPSO algorithm, show the capability of the MODFA for obtaining POS with uniform distribution and high quality.
1	MDPI Journal of Applied Science. (2019). https://doi.org/10.3390/app9010007	Ashkan Memari. Robiah Ahmad, Mohammad Reza Akbari Jokar, Abd. Rahman Abdul Rahim.	A New Modified Firefly Algorithm for Optimizing a Supply Chain Network Problem.	Modified the classical firefly algorithm such that makes a balance between exploitation and exploration. The purposed modified algorithm ranks and	Found metaheuristics parameters setting using a trial-and-error procedure. Recommended for a further study that could assess the effects of parameters' setting on the

				sorts the initial solutions.	performance of the proposed algorithm.
2	Elsevier Journal of Swarm and Evolutionary Computation Volume 48, August 2019, Pages 72-92 https://doi.org/10.1016/j.swevo.2019.03.010.	M.K.A. Ariyaratne, T.G.I. Fernando, S. Weerakoon.	Solving systems of nonlinear equations using a modified firefly algorithm (MODFA).	A modified firefly algorithm treating the problem as an optimization problem, which is capable of giving multiple root approximations simultaneously within a reasonable state space.	Almost all roots of a system of nonlinear equations for a reasonable search space can be found without prior initial guesses or without considering the differentiability or even the continuity of the equations in the system.
3	IEEE Access (Vol. 7) Page(s): 57424 - 57439 DOI: 10.1109/ACCESS.2019.2914534.	Chunfeng Wang, Xinyue Chu.	An Improved Firefly Algorithm with Specific Probability and Its Engineering Application.	To reduce computational time complexity, speed up the convergence, avoid oscillation in the iteration and overstep the local optimum, a novel firefly algorithm (pFA) was proposed.	The attraction among fireflies can be reduced, thus, it can avoid oscillation, Improve the precision of solution and speed up convergence. And the usage of opposite learning strategy makes the diversity of population increased and enhance exploration.
4	Elsevier Journal of Swarm and Evolutionary Computation Vol. 44, February 2019, Pages 828-839 https://doi.org/10.1016/j.swevo.2018.09.004.	Arijit Datta, Vimal Bhatia.	A near maximum likelihood performance modified firefly algorithm for large MIMO detection.	A stochastic bio-inspired meta-heuristic algorithm is proposed for large MIMO detection. Motivated by the bioluminescence of fireflies and uses a probabilistic metric to update solutions in the search space.	Simulation results reveal that the proposed algorithm outperforms unordered congestion control ant colony optimization, congestion control ant colony optimization, standard particle swarm optimization (PSO), binary PSO, memetic PSO, firefly algorithm.
5	J Intell Manuf **30**, 2545–2574 (2019). https://doi.org/10.1007/s10845-018-1419-6	Ivona Brajević, Jelena Ignjatović.	An upgraded firefly algorithm with feasibility-based rules for constrained engineering optimization problems.	An upgraded firefly algorithm (UFA) is proposed to further improve its performance in solving constrained engineering optimization problems.	Comprehensive experimental results show that the overall performance of the UFA is superior to the FA and its recently proposed variants.
6	2019 IEEE 6th International Conference on Engineering Technologies and Applied Sciences (ICETAS) DOI: 10.1109/ICETAS48360.2019.9117417.	Ariel O. Gamao, Bobby D. Gerardo, Ruji P. Medina.	Modified Mutated Firefly Algorithm.	A Modified Mutated Firefly Algorithm (MMFA) was developed to optimize the convergence time, employing a stochastic approach with increased convergence time.	The MFA converges faster than the standard FA using the 40:40 formula. With this, only the top 40 percent and bottom 40 percent of the fireflies join in the mutation process.
7	Journal of Intelligent & Fuzzy Systems, Vol. 36, no. 2, pp. 1547-1562, 2019. DOI: 10.3233/JIFS-181936.	Wahid Fazli, Alsaedi Ahmed Khalaf Zager, Ghazali Rozaidaa.	Using improved firefly algorithm based on genetic algorithm crossover operator for solving optimization problems.	The crossover operator of genetic algorithm (GA) is incorporated into firefly position changing stage that results in better exploitation capability which improves the local convergence rate resulting in better solution quality.	Compared with standard FA, GA, artificial bee colony (ABC) and ant colony optimization (ACO) algorithms it performed better in terms of convergence rate for various types of minimization and maximization optimization functions.
8	Arabian Journal for Science and Engineering Vol. 44, pages 4027–4047 (2019). https://link.springer.com/journal/13369.	Fazli Wahid, Rozaida Ghazali, Lokman Hakim Ismail.	Improved Firefly Algorithm Based on Genetic Algorithm Operators for Energy Efficiency in Smart Buildings.	Introducing genetic algorithm (GA) operators namely selection, mutation and crossover operators in the firefly position stage of the standard FA.	The statistical analysis shows the efficiency of the proposed model for power consumption minimization and user comfort maximization.

9	IEEE Access (Vol. 9) Page(s): 1918 - 1939 DOI: 10.1109/ACCESS.2020.3046910.	Sheroze Liaquat, Muhammad Salman Fakhar, Syed Abdul Rahman Kashif, Akhtar Rasool, Omer Saleem, Muhammad Fahad Zia, Sanjeevikumar Padmanaban.	Application of Dynamically Search Space Squeezed Modified Firefly Algorithm to a Novel Short Term Economic Dispatch of Multi-Generation Systems.	Proposed multi-update position criteria to enhance the exploration properties of the conventional firefly technique while including the effect of the global best solution on the movement of the fireflies in the search space of the objective function.	The performance of the modified firefly is superior to its conventional counterpart as the evaluation parameters of the modified firefly converge to relatively lower value as compared to the parameters of the simple firefly algorithm.
0	Expert Systems with Applications, 149(113340), 113340. doi:10.1016/j.eswa.2020.113340	Wu, J., Wang, Y.-G., Burrage, K., Tian, Y.-C., Lawson, B., & Ding, Z.	An improved firefly algorithm for global continuous optimization problems.	An adaptive logarithmic spiral-Levy FA (AD-IFA) that strengthens the LF-FA's local exploitation and accelerates its convergence.	In this research, the logarithmic-spiral path has been applied in the FA optimizer to strengthen the exploitation in local space and accelerate the convergence of the search process.
1	2020 International Wireless Communications and Mobile Computing (IWCMC). Presented at the 2020 International Wireless Communications and Mobile Computing (IWCMC), Limassol, Cyprus. doi:10.1109/iwcmc48107.2020.9148087	Zivkovic, M., Bacanin, N., Tuba, E., Strumberger, I., Bezdan, T., & Tuba, M.	Wireless Sensor Networks Life Time Optimization Based on the Improved Firefly Algorithm	Wireless sensor network lifetime maximization with the goal to improve energy consumption throughout the network by balancing the energy consumption overall nodes,	Performed better when evaluated by comparing it to the LEACH, basic firefly algorithm and particle swarm optimization, that were all tested on the same network infrastructure model.
2	Expert Systems with Applications, 150(113216), 113216. doi:10.1016/j.eswa.2020.113216	Wang, W.-C., Xu, L., Chau, K.-W., & Xu, D.-M.	Yin-Yang firefly algorithm based on dimensionally Cauchy mutation.	A Yin-Yang firefly algorithm (YYFA) based on dimensionally Cauchy mutation is proposed for performance improvement of FA.	Nonparametric statistical tests on the results demonstrate that YYFA provides highly competitive performance in terms of the tested algorithms. Also the application in constrained engineering optimization problems shows the practicability of YYFA algorithm.
3	International Journal of Digital Crime and Forensics (IJDCF) 13(2) 2021 |Pages: 17 -26 DOI: 10.4018/IJDCF.2021030105.	Partha Ghosh, Dipankar Sarkar, Joy Sharma, Santanu Phadikar.	An Intrusion Detection System Using Modified-Firefly Algorithm in Cloud Environment.	This Modified Firefly Algorithm is achieved by blending the idea of three different data mining methods. These methods includes PSO, FA and Fuzzy Logics.	The proposed MFA produces better optimum feature subset than the normal FA.
4	Journal of Operation and Automation in Power Engineering Vol. 9, No. 1, Apr. 2021, Pages: 68-79 http://joape.uma.ac.ir	A. Rastgou1, S. Bahramara.	An Adaptive Modified Firefly Algorithm to Unit Commitment Problem for Large-Scale Power Systems.	A new modification approach based on the mutation and crossover operators as well as an adaptive formulation is applied as an adaptive modified firefly algorithm (AMFA).	The method is applied on some case studies, a typical 10-unit test system, 12, 17, 26, and 38 generating unit systems, and IEEE 118-bus test system, all with a 24-hour scheduling horizon. Results shows the effectiveness and fastness of the applied method.
5	Journal of Web Engineering, Vol. 20 1, 33–52. doi: 10.13052/jwe1540-9589.2012 © 2021 River Publishers.	M. Subramania, A. Kathirvel, E. Sabitha, H. Anwar Basha.	Modified Firefly Algorithm and Fuzzy C-Mean Clustering Based Semantic Information Retrieval.	With the intention of enhancing the query searching time, the research system implemented a Modified Firefly Algorithm (MFA) adapted with Intelligent Ontology and Latent Dirichlet Allocation based	The structural design of the presented method is flexible to handle with user defined ontology which handles the generic query using standard query languages. The experimentation outcomes prove that the presented system attains improved performance when

				Information Retrieval (IOLDAIR) model.	matched up with the previous methodology.
6	IEEE 2021 3rd International Conference on Research and Academic Community Services (ICRACOS) DOI: 10.1109/ICRACOS53680.2021.9701981.	Asnun Parwanti, Slamet Imam Wahyudi, Moh Faiqun Ni'Am.	Modified Firefly Algorithm for Optimization of the Water Level in the Tank.	This study focused on the Modified Firefly Algorithm (MFA) artificial intelligence method which is designed for water levels.	The output Flow result obtained the smallest overshot value in the PID-MFA model =1.532 pu, the smallest undershot in the model PID-MFA =0.201 pu. Thus, the best controller model is PID-MFA.
7	Springer Journal of Neural Computing and Applications volume 34, pages 2455–2471 (2022). doi:10.1007/s00521-021-06544-z	Abbas Abbaszadeh Shahri, Mohammad Khorsand Zak, Hossein Abbaszadeh Shahri.	A modified firefly algorithm applying on multi-objective radial-based function for blasting.	Introduced a modified firefly algorithm (MFA) using expectation value and generalized weighted average of a random brightness and then evaluated with different benchmark functions.	The introduced MFA as a reliable and feasible tool with accurate enough response can effectively be applied to multi-objective problems. Implemented sensitivity analyses scored the distance and burden as the most and least influences factors on predicted outputs.
8	Elsevier Journal of Decision Analytics Journal Vol. 5, December 2022, 100125. https://doi.org/10.1016/j.dajour.2022.100125	Mojtaba Ghasemi, Soleiman kadkhoda Mohammadi,Mohsen Zare, Seyedali Mirjalili, Milad Gil, Rasul Hemmati.	A new firefly algorithm with improved global exploration and convergence with application to engineering optimization.	Proposed a novel FA, called firefly algorithm 1 to 3 (FA1→3), via different types of movements of fireflies in an attempt to improve the global exploration and convergence characteristics of FA.	It has been applied to six real-world engineering problems to show the optimization capability, robustness, and efficacy of FA1→3 in comparison with modern algorithms As per simulations, FA1→3 has provided suitable performance and higher accuracy than traditional and modified algorithms.
9	MDPI Journal of Materials 2022, 15(23), 8630; https://doi.org/10.3390/ma15238630 https://www.mdpi.com/journal/materials.	Zhouquan Feng, Wenzan Wang, Jiren Zhang.	Probabilistic Structural Model Updating with Modal Flexibility Using a Modified Firefly Algorithm.	Proposed a Bayesian model updating method with modal flexibility was presented, where a modified heuristic optimization algorithm named modified Nelder–Mead firefly algorithm (m-NMFA) was proposed to find the most probable values (MPV) of model parameters for the maximum a posteriori probability (MAP) estimate.	The proposed Bayesian model updating method has the advantages of high precision, fast convergence, and strong robustness in MPV finding and the ability of parameter uncertainty quantification.
0	International Journal of Engineering and Management Research e-ISSN: 2250-0758 | p-ISSN: 2394-6962 Vol. 12, Issue-6, (December 2022) Pages 189 -197. www.ijemr.net https://doi.org/10.31033/ijemr.12.6.26.	Gayathri Devi Karunagaran, R.S Mishra, A.K. Madan.	A comprehensive review of recent variants and Modifications of Firefly Algorithm.	Presented a broad review on two Swarm intelligence (SI) algorithms: (1) Firefly Algorithm (FA) (2) Flower Pollination Algorithm (FPA).	This review has justified that FA is a potentially powerful and useful tool for solving different optimization problems in a diverse range of applications.

III. Results and Discussion:

Over time, 2013 to 2022, various modified versions of the Firefly Algorithm have been developed to enhance its performance in solving complex engineering problems. There are numerous research papers, articles, and conference papers that focused on the applications and modifications of the Firefly Algorithm in various engineering fields. These individual studies and papers often detail the applications of modified Firefly Algorithms in specific engineering problems, showcasing their performance in optimization, control systems, structural design, mechanical engineering, electrical engineering, and other related fields. They often present comparisons

with other optimization techniques and demonstrate the efficiency and efficacy of the modified Firefly Algorithms in different contexts.

IV. Conclusion:

From these individual studies, it can be concluded that the modified Firefly Algorithms have demonstrated promising results in various engineering applications, showing effectiveness in optimizing complex problems. They have been utilized in fields such as structural design, mechanical engineering, electrical engineering, and more. These algorithms often exhibit competitive performance compared to other metaheuristic and optimization techniques.

Empirically it is acceptable to draw conclusions from these studies as highlighted in several key points below:

1. **Efficiency in Optimization:** Modified Firefly Algorithms have shown efficacy in optimizing complex engineering problems, providing competitive results in terms of convergence speed and solution quality.
2. **Malleability and Flexibility:** The modifications and hybridizations of the Firefly Algorithm showcase its adaptability to different problem domains. Variants have been tailored to handle multi-objective optimization, constraint handling, and parallel processing, indicating versatility.
3. **Explicit Applications:** Studies have detailed the successful application of these algorithms in various fields, emphasizing their potential in aiding structural design, control systems, feature selection in machine learning, antenna design, power system optimization, and more.
4. **Necessity for Further Research:** While showing promise, these studies also point towards the need for further research to explore the algorithm's performance across a wider array of engineering problems and to optimize the algorithms themselves for specific problem types.

In conclusion, while there might not be a comprehensive review available, the individual studies suggest that modified Firefly Algorithms hold significant promise in addressing complex engineering optimization problems. Nonetheless, ongoing research and development are necessary to further refine these algorithms and explore their performance across various engineering applications.

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