IMPROVED FLOWER POLLINATION OPTIMIZATION ALGORITHM BASED ON SWAP OPERATOR AND DYNAMIC SWITCH PROBABILITY SELECTION

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DEDICATION

With Love and Trillion Thanks,

To my beloved mother and father who never stopped encouraging me to study further and my success is their only dream

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PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

Meta-heuristic algorithms have become popular in finding optimal solutions for nonlinear complex problems. These algorithms belong to stochastic and non-deterministic classes, have some problems with exploration or exploitation. The researchers used different strategies to tackle these issues. The flower pollination algorithm (FPA) is one of the more popular nature-inspired search algorithms. It has powerful global searchability to find the best optimal solution of real-world problems by using levy flight to explore the search space. Moreover, its single tuning parameter and simple mathematical model make it easier to implement. However, the flower pollination algorithm has a few drawbacks which are partially addressed by the practitioners. The first issue is regarding the balance between global pollination and local pollination, which may negatively affect the optimality of solution. Secondly, the FPA has a diversification problem which may leads to premature convergence of the optimal solution. This research proposed an algorithm which is based on dynamic switch probability to control the balance between exploration and exploitation which increases its searchability. The swap operator has been added in local pollination to enhance the exploitation behavior of pollens during the pollination process. Furthermore, it is hybridized with the Pattern Search algorithm to ensure the optimality of the solution. The performance of the proposed algorithm (IFPDSO-PS) has been evaluated on seventeen standard test functions and compared with the stated meta-heuristic algorithms. The statistical tools (Absolute Mean Error & Fried Man) are used to rank the performance of all algorithms. The proposed algorithm is ranked first among the stated algorithms with respect to its performance in getting the optimal solution.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRAK

Algoritma meta-heuristik telah menjadi popular dalam mencari penyelesaian optimum untuk masalah kompleks bukan linear. Algoritma ini tergolong dalam kelas stokastik dan bukan deterministik, mempunyai beberapa masalah dengan penerokaan atau eksploitasi. Para penyelidik menggunakan strategi yang berbeza untuk menangani isu ini. Algoritma pendebungaan bunga (FPA) ialah salah satu daripada algoritma carian yang diilhamkan oleh alam semula jadi yang lebih popular. Ia mempunyai kebolehcarian global yang berkuasa untuk mencari penyelesaian optimum terbaik bagi masalah dunia sebenar dengan menggunakan penerbangan levi untuk meneroka ruang carian. Lebih-lebih lagi, parameter penalaan tunggal dan model matematik mudah menjadikannya lebih mudah untuk dilaksanakan. Walau bagaimanapun, algoritma pendebungaan bunga mempunyai beberapa kelemahan yang sebahagiannya ditangani oleh pengamal. Isu pertama adalah mengenai keseimbangan antara pendebungaan global dan pendebungaan tempatan, yang mungkin menjejaskan optimum penyelesaian secara negatif. Kedua, FPA mempunyai masalah kepelbagaian yang boleh membawa kepada penumpuan pramatang bagi penyelesaian optimum. Penyelidikan ini mencadangkan satu algoritma yang berasaskan kebarangkalian suis dinamik untuk mengawal keseimbangan antara penerokaan dan eksploitasi yang meningkatkan kebolehcariannya. Operator swap telah ditambah dalam pendebungaan tempatan untuk meningkatkan tingkah laku eksploitasi debunga semasa proses pendebungaan. Tambahan pula, ia dihibridkan dengan algoritma Carian Corak untuk memastikan penyelesaian yang optimum. Prestasi algoritma yang dicadangkan (IFPDSO-PS) telah dinilai pada tujuh belas fungsi ujian standard dan dibandingkan dengan algoritma meta-heuristik yang dinyatakan. Alat statistik (Absolute Mean Error & Fried Man) digunakan untuk menilai prestasi semua algoritma. Algoritma yang dicadangkan berada di kedudukan pertama antara algoritma yang dinyatakan berkenaan dengan prestasinya dalam mendapatkan penyelesaian yang optimum.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CONTENTS

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF SYMBOLS AND ABBREVIATIONS

SUMT	-	Sequential Unconstrained Minimization Techniques
KKT	-	Kuhn- Tucker
ACO	-	Ant Colony Optimization
WSNs	-	Wireless Sensor Networks
PSO	-	Particle Swarm Optimization
VC	-	Velocity Clamping
FA	-	Fire Fly Algorithm
HBA	-	Honey Bee Algorithm
ABC	-	Artificial Bee Colony
PS	-	Pattern Search
SA	-	Simulating Annealing
FPA	-	Flower Pollination Algorithm
LSGS	-	Local Self Adaptive Greedy Strategy
GEOL	-	Global Elite Opposition based Learning Strategy
GA	-	Generic Algorithm
FCM	-	Fuzzy C-mean
IFPDSO	-	Improved Flower Pollination with Dynamic Switch Probability and Swap Operator
IFPDSO-PS	-	Hybrid Improved Flower pollination and Pattern Search
WOA	-	Whale Optimization Algorithm
GWO	-	Grey Wolf Optimizer
KNN	-	K-Nearest Neighbour
ED	-	Economic Dispatch
MAE	-	Mean Absolute Error

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF PUBLICATIONS

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PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Research background

In computer science particularly in operations research and mathematics, optimization is the procedure to find the optimal solution by comparing number of solutions iteratively. In other words, optimization is a technique of making something (a design, system, or decision) as perfect, functional and effective as possible. In optimization, mathematical procedures are involved in finding the maximum or minimum value of the function with a given set of inputs. Optimization provides an elegant mixture of theory and applications where the theory uses some elements of basic calculus and elementary linear algebra and continues with functional and complex analysis. Optimization has been applied in many industries such as in the information technology industry, Medical Science, Bio-informatics, medical images, Engineering and Economics. In this era, optimization has become one of the growing research fields for researchers, practitioners, and students to study, apply, and conduct research.

The Optimization algorithms have been divided into two distinct types, gradient base or (dependent) techniques and gradient free or (independent) techniques. The gradient base techniques use specific rules in getting an optimum solution as compare to other promising solutions while the gradient free techniques use random process to get the optimum solution. This research focus on nature inspired metaheuristic (gradient free) non deterministic techniques. These techniques can be further divided into main three subtypes: Bio inspired, Swarm intelligence inspired, physics-based and chemistry-based. Swarm intelligence is one of the popular field of artificial intelligence (AI) over the last three decades (Hussain *et al.,* 2019; Komsiyah *et al.,* 2016) which has been used in many applications in solving complex

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

optimization problems. Swarm intelligence is inspired by the collective behaviors of social swarms of the ant colony, school of fish, bees, worms, termites, and a flock of birds, in achieving their goals. The bio-inspired techniques are based on biological evolutionary process. These new approaches use biological mechanism like immune system, genetic evolution and clonal selection for survival of the fittest.

In the meta-heuristic approaches, exploration (diversification) is the process of finding the different solutions in the search space. Whereas, the exploitation (intensification) is the process of focusing the search process in the neighborhood for good solutions by exploiting the information obtained (Diab and El-Sharkawy, 2016). In each meta-heuristic algorithm, the process of searching the best global solution depends on the balancing between exploration and exploitation (Nabil, 2016).

In the nature-inspired algorithms, the Flower Pollination Algorithm (FPA) is one of the meta-heuristic algorithms which has single tunning parameter and simple mathematical model. It is easy to understand the mathematical processes of FPA as compare to other metaheuristic algorithms which attracts the practitioners to apply it, in various domains of research. It has been applied in the domains of engineering, education and medical to get near optimal solution. The flower pollination algorithm was developed by Xin-She Yang (2012), inspired by the pollination behaviors of flower to pollinate for reproduction according to the principles of survival of the fittest (Yang, 2014, Karamanoglu & He, 2014, Emary *et al.,*2016). The consistency of flower in reducing the costs of investigation has helped the pollinators to increase the transferring time of pollen, which maximizes the process of production. The limited memory of pollinators helps flower consistency to eliminate its learning and investigation which represents the incremental steps that depend on the difference or similarity of two flowers.

The flower pollination algorithm (FPA) has some advantages over other metaheuristic algorithms due to having single controlling parameter to select exploration (global search) or exploitation (local search) (He *et al*., 2018). In the literature studies, Markov theory has proved the FPA as the global best algorithm (He *et al*., 2017a). However, the flower pollination algorithm also faces some issues for solving different complex multimodal optimization problems. First one is the high switch probability value 0.8 has been used in basic FPA which causes an imbalance between exploration and exploitation (Liu *et al.*, 2019).The balance between exploration and exploitation means to control its searchability according to the nature

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

of the problem. In optimization problems search space varies which required more exploration as compare to exploitation to get global best solution in the whole search space. The flower pollination algorithm also face the problem of premature convergence in exploitation when the problem is multimodal (Zhou and Wang, 2016, Sreenivasa Rao *et al.,* 2018).

In addressing the problem of balancing between the exploration and exploitation, numbers of researchers introduced modifications in the standard FPA to enhance its efficiency. There are some modified versions of FPA that have been introduced by the authors (Lazim *et al.*, 2017, Alyasseri *et al.*, 2018, Mishra and Deb, 2019). All those authors have addressed a single modification in some parts of the FPA e.g. some authors have modified levy's flight with random walk in standard FPA to enhance its searchability, few of the authors brought some changes in switch probability by fuzzy inference system and some replace it with exponential dynamic switch probability (Valenzuela *et al*., 2017) (Wong & Ming, 2019).Whereas other authors modified in the step size of the levy's flight and uniform distribution parameter (He *et al.*, 2017). Some authors have addressed the issue mentioned earlier by using mutation and crossover operator in basic FPA but failed to handle all those problems that have been identified (Abdel-baset & Hezam, 2015).

Furthermore, many researchers have hybridized the FPA with other meta-heuristic and dynamic algorithms to balance the exploration and exploitation of the FPA. The Flower Pollination Algorithm has been used for exploration to hybridize with other meta-heuristic algorithms (Kherfane *et al.*, 2014, Alyasseri *et al.*, 2018, Sidhu and Mehta, 2017, Abdel-Fattah *et al.*, 2016, Lazim *et al.*, 2017). In this research an improved Flower Pollination algorithm has been proposed for exploration and Pattern Search (local search) optimization algorithm for exploitation to tackle the issues of diversification and premature convergence appropriately.

1.2 Motivation for research

In the last three decades a number of metaheuristic algorithms have been developed to handle the enormous complexity and high computational cost of real-world problems. In the literature studies, it has been identified that these algorithms work well in practice but most of them do not have theoretical analysis. Therefore, it was rarely

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

known how to improve their working mechanism. The standard Flower Pollination Algorithm (FPA) has been analyzed theoretically to identify its strengths and weaknesses which are associated with it in solving complex optimization problems. This information helps in this research to understand the strength of FPA and its drawbacks. The basic flower pollination algorithm belongs to the class of global search algorithms. Therefore, this research has improved the basic FPA and hybrid it with local search algorithm (PS) to address the issues of searchability and premature convergence to enhance its performance.

1.3 Problem statement

The standard Flower Pollination Algorithm (FPA) has become popular among researchers; however, some drawbacks have been associated with it in solving complex optimization problems. These drawbacks have been listed below:

a) The premature convergence of algorithm in multi-modal optimization problems being trapped in local optima may affect the optimality of the solution.

b) The fixed switch probability creates imbalance between global pollination and local pollination which affects the searchability and performance in getting the optimum solution.

c) If the best solution is obtained in maximum number of iterations in FPA, there is still need for further exploring and exploiting to get the universal best optimal solution.

1.4 Research objectives

The main task of this research is to develop an improved flower pollination algorithm by handling the local optimum with swap operator, dynamic switch probability for balancing the exploration and exploitation, and hybridizing it with pattern search for improving the performance. The following main objectives have been proposed for this research:

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

a) To propose an improved flower pollination algorithm by introducing swap operator within local pollination for diversification of promising solutions to avoid the premature convergence for improving the optimality of solution.

b) To further enhance the proposed method in (a) by modifying the fixed switch probability to dynamic switch probability for balancing the exploration and exploitation to enhance the searchability of the flower pollination algorithm to improve the performance of FPA.

c) To enhance the quality of solution hybridized the pattern search approach and to evaluate the performance of the proposed method by comparing with prevailing meta-heuristic algorithms, standard flower pollination algorithm on some selected benchmark functions and real-life power generation (electrical engineering) problems.

1.5 Scope of research

The proposed version of the hybrid flower pollination algorithm (IFPDSO-PS) has been evaluated on single and multi-objective optimization problems (Economic load dispatch to minimize the cost of production, Valve point Loading effect, Transmission loses minimization and Minimizing the emissions, Distributed Generation to minimize loses, wireless sensor network (Sidhu and Mehta, 2017, Abdelaziz *et al.*, 2016, Hajjej *et al.*, 2016; Sakthivel *et al.*, 2016). The proposed algorithm has been evaluated on standard benchmark functions (Khursheed *et al.*, 2020, Kamboh *et al.*, 2021) and real-world optimization problems (Yang, 2015). The performance of the proposed algorithm has been compared and analyzed with the standard flower pollination algorithm, different improved flower pollination algorithms, hybrid flower pollination algorithms, simulated annealing algorithm, artificial bee colony algorithm, Whale optimization algorithm, genetic algorithm, grey wolf optimizer and some other optimization techniques. The criteria of assessment for the proposed algorithm are based on mean and standard deviation (SD) as well as Mean Absolute Error and Friedman statistical tool have been used to rank the algorithms to measure its performance. All the results and simulations have been discussed in Chapter 4 to justify the robustness (in the sense of quality of solution) of the improved hybrid flower

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

pollination algorithm (IFPDSO-PS) with dynamic switch probability and swap operator.

1.6 Outlines of the thesis

The thesis consists of five chapters including the introduction and the conclusion. Following is the brief outline of each chapter. First chapter consists of brief introduction of historical background of study, motivation for research, problem statement, scope of research, aims and objective of study. The second chapter describes the concept of optimization and detailed review of Meta-heuristic algorithms and the advancements in Flower Pollination algorithm have been discussed in detail. After deep review of flower pollination algorithm, gaps are identified and further improvements have been identified. In Chapter 3, the research methodology of the proposed algorithm has been explained thoroughly. The identified gaps in FPA are adjusted to improve the searchability and convergence of the basic algorithm. The pattern search algorithm has been discussed to hybridize with the improved flower pollination algorithm. In Chapter 4, the proposed hybrid algorithm is tested on standard benchmark test functions, and its performance is compared with other stated meta-heuristic algorithms. The algorithm is also tested on economic dispatch problem. The last chapter summarizes the research contributions and recommendations for future work.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The theory about nature-inspired algorithms explains the main process (natural selection, reproduction, and survival) of living creatures on earth which try its best to adapt the demands of the environment. If an organism has succeeded in adapting to such an environment, then it has the most chance to survive. This also shows that these entities are able to adapt the fluctuations of the environment. This is why these entities have more chance to survive longer and to spread their genotype (Yusoff *et al*., 2011, Xue *et al.*, 2016).

In the last three decades a number of optimization algorithms have been developed metaheuristic to handle the enormous complexity and high computational cost of real-world problems. The deterministic algorithms produce same output against any particular input but the non-deterministic algorithms can produce different output for same input in every run. However, hard optimization problems are those problems that cannot be solved by deterministic (exact) method within the limits of time. These problems can be divided into many categories such as continuous or discrete, mono or multi-objective, constrained or unconstrained, and static or dynamic. Among those optimization methods, the nature-inspired meta-heuristic techniques are more applicable to get possible solution. The nature-inspired meta-heuristic methods are divided into four categories: Evolutionary algorithms (EA),Swarm intelligence, Physics rule base algorithms and Human behavior base algorithms (Wierstra *et al.*, 2008, Sun *et al.*, 2019). Most of the optimization methods are showing the common problems related to comprehensive coverage of change in the behavior of algorithms with respect to its performance (Sun *et al.*, 2020).

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

This chapter explains on previous literatures that show the classification of optimization and global overview of meta-heuristic optimization techniques. The main focus of this chapter is to identify the gaps and limitations of the meta-heuristic methods. Finally, the research related to the topic has been reviewed to find future research promising paths. This chapter does not only target on a single problem but focuses on more practical problems.

2.2 Optimization

The main aim of optimization is searching for optimality which involves a large number of problems. Optimization problems can be named and classified in different ways. Because of these optimization techniques vary significantly from problem to problem. The use of same approach is not possible for different problems because the complexity of optimization problems mostly depends on the form of the objective function and its constraints.

The generic mathematical form of most optimization problems:

Minimize/Maximize: $f(x)$

$$\begin{aligned} \text{Subject to: } g_j(x) &\leq 0 && j = 1,2,3 \ldots \ldots \ldots \ldots \ldots \ldots . m \\ h_k &= 0 && k = 1,2,3 \ldots \ldots \ldots \ldots \ldots \ \ldots \ldots p \\ x_i l \ \leq x_i &\leq x_i u && i = 1,2,3 \ldots \ldots \ldots \ldots \ldots \ldots \ldots . . n \end{aligned} \tag{2.1}$$

Where, $f(x)$ represents the fitness (or goal) function, $g_j(x)$ inequality constraints and h_k (x) equality constraints of objective function are represented in equation 2.1. Where, ‘j’ and ‘k’ are the number of constraints with limits ‘m’ and ‘p’ respectively. The vector ‘x’ represents the ‘n’ design variables to find the optimum. The searchable design space is represented by the upper and lower bounds $x_i u$ and $x_i l$, of the design variables respectively (Yar *et al*., 2016).

In general case, the objective functions and constraints can be linear or nonlinear and can be explicit or implicit functions. Implicit functions normally appear, when a numerical simulation (e.g., a finite element simulation) is used to evaluate a fitness function (e.g., a stress value). Also, the design variables should not to be continuous. Optimization problems referred to some or all of the design variables restricted to integer or discrete values (Ratniyomchai *et al.*, 2016).

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

REFERENCES

Abdel-baset, M., & Hezam, I. M. (2015). An Effective Hybrid Flower Pollination and Genetic Algorithm for Constrained Optimization Problems. *Advanced Engineering Technology and Application*, *34*(2), 27–34.

Abdel-Baset, M., & Hezam, I. M. (2016). A hybrid flower pollination algorithm for solving ill-conditioned set of equations. *International Journal of Bio-Inspired Computation*, *8*(4), 215–220.

Abdel-Basset, M., El-Shahat, D., El-Henawy, I., & Sangaiah, A. K. (2018). A modified flower pollination algorithm for the multidimensional knapsack problem: human-centric decision making. *Soft Computing*, *22*(13), 4221–4239.

Abdel-Fattah Sayed, S., Nabil, E., & Badr, A. (2016). A binary clonal flower pollination algorithm for feature selection. *Pattern Recognition Letters*, , 21–27.

Abdelaziz, A. Y., Ali, E. S., & Abd Elazim, S. M. (2016a). Combined economic and emission dispatch solution using Flower Pollination Algorithm. *International Journal of Electrical Power and Energy Systems*, *80*, 264–274.

Abdelaziz, A. Y., Ali, E. S., & Abd Elazim, S. M. (2016b). Implementation of flower pollination algorithm for solving economic load dispatch and combined economic emission dispatch problems in power systems. *Energy*, *101*, 506–518.

Abi, S., Benhala, B., Bouyghf, H., & Fakhfakh, M. (2019). A Comparative Study between ACO and de Techniques by Numerical Functions Optimization. *2019 International Conference on Optimization and Applications, ICOA 2019*, 1–6.

Ackley, D. H. (1987). An empirical study of bit vector function optimization. *Genetic Algorithms and Simulated Annealing*, *1*, 170–204.

Agrawal, P., Abutarboush, H. F., Ganesh, T., & Mohamed, A. W. (2021). Metaheuristic algorithms on feature selection: A survey of one decade of research

PTTAUTHM
PERPUSTAKAAN TUNKU TUN AMINAH

(2009-2019). *IEEE Access*, *9*, 26766–26791.

Ahmad RazlanYusoff, M. R. Z. M. S., & Taib, and M. Y. (2011). Literature Review of Optimization Techniques for. *Journal of Mechanical Engineering and Sciences (JMES)*, *1*(December), 47–61.

Alyasseri, Z. A. A., Khader, A. T., Al-Betar, M. A., Awadallah, M. A., & Yang, X. S. (2018). Variants of the flower pollination algorithm: A review. *Studies in Computational Intelligence*, *744*, 91–118.

Bergmann, R., & Herzog, R. (2019). *INTRINSIC FORMULATION OF KKT CONDITIONS AND Copyright © by SIAM . Unauthorized reproduction of this article is prohibited .* *29*(4), 2423–2444.

Chakraborty, D., Saha, S., & Dutta, O. (2015). DE-FPA: A hybrid differential evolution-flower pollination algorithm for function minimization. *2014 International Conference on High Performance Computing and Applications, ICHPCA 2014*.

Chakraborty, D., Saha, S., & Maity, S. (2015). Training feedforward neural networks using hybrid flower pollination-gravitational search algorithm. *2015 1st International Conference on Futuristic Trends in Computational Analysis and Knowledge Management, ABLAZE 2015*, 261–266.

Chen, X., Yu, L., Wang, T., Liu, A., Wu, X., Zhang, B., Lv, Z., & Sun, Z. (2020). Artificial intelligence-empowered path selection: A survey of ant colony optimization for static and mobile sensor networks. *IEEE Access*, 71497–71511.

Chiroma, H., Shuib, N. L. M., Muaz, S. A., Abubakar, A. I., Ila, L. B., & Maitama, J. Z. (2015). A review of the applications of bio-inspired Flower Pollination Algorithm. *Procedia Computer Science*, *62*(Scse), 435–441.

Collignan, A., Pailhes, J., & Sebastian, P. (2011). Design optimization: management of large solution spaces and optimization algorithm selection. *IMProVe*.

Curtis, F. E., & Nocedal, J. (2018). *Optimization Methods for Large-Scale Machine Learning ∗*. *60*(2), 223–311.

Curtis, F. E., & Robinson, D. P. (2019). Exploiting negative curvature in deterministic and stochastic optimization. *Mathematical Programming*, *176*(1–2), 69–94.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Denzel, A., & Kästner, J. (2020). Hessian Matrix Update Scheme for Transition State Search Based on Gaussian Process Regression. *Journal of Chemical Theory and Computation*, *16*(8), 5083–5089.

Diab, N., & El-Sharkawy, E. (2016). Recent Advances in Flower Pollination Algorithm. *International Journal of Computer Applications Technology and Research*, *5*(6), 338–346.

Draa, A. (2015). On the performances of the flower pollination algorithm - Qualitative and quantitative analyses. *Applied Soft Computing Journal*, *34*, 349–371.

Dubey, H. M., Pandit, M., & Panigrahi, B. K. (2015). A Biologically Inspired Modified Flower Pollination Algorithm for Solving Economic Dispatch Problems in Modern Power Systems. *Cognitive Computation*, *7*(5), 594–608.

El-Ashmawi, W. H., Ali, A. F., & Tawhid, M. A. (2019). An improved particle swarm optimization with a new swap operator for team formation problem. *Journal of Industrial Engineering International*, *15*(1), 53–71.

Emary, E., Zawbaa, H. M., Hassanien, A. E., & Tolba, M. F. (2016). 6th International Conference on Innovations in Bio-Inspired Computing and Applications, IBICA 2015. *Advances in Intelligent Systems and Computing*, *424*, 1–586.

Gharehchopogh, F. S., & Gholizadeh, H. (2019). A comprehensive survey: Whale Optimization Algorithm and its applications. *Swarm and Evolutionary Computation*, *48*, 1–24.

Griewank, A. O. (1981). Generalized descent for global optimization. *Journal of Optimization Theory and Applications*, *34*, 11–39.

Hajjej, F., Ejbali, R., & Zaied, M. (2016). *An Efficient Deployment Approach for Improved Coverage in Wireless Sensor Networks Based on Flower Pollination Algorithm*. 117–129.

He, X. S., Wang, F., Wang, Y., & Yang, X. S. (2018). Global convergence analysis of cuckoo search using markov theory. *Studies in Computational Intelligence*, *744*, 53–67.

He, X., Yang, X. S., Karamanoglu, M., & Zhao, Y. (2017a). Global Convergence Analysis of the Flower Pollination Algorithm: A Discrete-Time Markov Chain

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Approach. *Procedia Computer Science*, *108*, 1354–1363.

He, X., Yang, X. S., Karamanoglu, M., & Zhao, Y. (2017b). Global Convergence Analysis of the Flower Pollination Algorithm: A Discrete-Time Markov Chain Approach. *Procedia Computer Science*, *108*, 1354–1363.

Hussain, K., Mohd Salleh, M. N., Cheng, S., & Shi, Y. (2018). Metaheuristic research: a comprehensive survey. *Artificial Intelligence Review*, 1–43.

Hussain, K., Mohd Salleh, M. N., Cheng, S., & Shi, Y. (2019). Metaheuristic research: a comprehensive survey. *Artificial Intelligence Review*, *52*(4), 2191–2233.

Hussain, S., Al-Hitmi, M., Khaliq, S., Hussain, A., & Saqib, M. A. (2019). Implementation and comparison of particle swarm optimization and genetic algorithm techniques in combined economic emission dispatch of an independent power plant. *Energies*, *12*(11).

Kamboh, M. I., Mohd Nawi, N., & Bt. Mohamad, R. (2021). An improved flower pollination solution for economic dispatch with valve point effect. *Indonesian Journal of Electrical Engineering and Computer Science*, *22*(2), 629.

Karaboga, D. (2010). Artificial bee colony algorithm. *Scholarpedia*, *5*(3), 6915.

Karaboga, D., & Basturk, B. (2008). On the performance of artificial bee colony (ABC) algorithm. *Applied Soft Computing Journal*, *8*(1), 687–697.

Kherfane, N., Kherfane, R. L., Younes, M., & Khodja, F. (2014). Economic and Emission Dispatch with renewable energy using HSA. *Energy Procedia*, *50*, 970–979.

Khursheed, M. U. N., Alghamdi, M. A., Nadeem Khan, M. F., Khan, A. K., Khan, I., Ahmed, A., Kiani, A. T., & Khan, M. A. (2021). PV Model Parameter Estimation Using Modified FPA with Dynamic Switch Probability and Step Size Function. *IEEE Access*, *9*, 42027–42044

Khursheed, M. U. N., Nadeem, M. F., Khalil, A., Sajjad, I. A., Raza, A., Iqbal, M. Q., Bo, R., & Rehman, W. U. (2020). Review of Flower Pollination Algorithm: Applications and Variants. *2020 International Conference on Engineering and* Emerging Technologies, ICEET 2020, 1–6.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Kizielewicz, B., & Sałabun, W. (2020). A new approach to identifying a multi-criteria decision model based on stochastic optimization techniques. Symmetry, 12(9).

Komsiyah, S., Suhartono, D., & Budiyanto. (2016). Optimization economic dispatch with transmission losses using by firefly algorithm. AIP Conference Proceedings, 1746.

Korashy, A., Kamel, S., Jurado, F., & Youssef, A. R. (2019). Hybrid Whale Optimization Algorithm and Grey Wolf Optimizer Algorithm for Optimal Coordination of Direction Overcurrent Relays. Electric Power Components and Systems, 47(6–7), 644–658.

Lazim, D., Zain, A. M., Bahari, M., & Omar, A. H. (2017). Review of modified and hybrid flower pollination algorithms for solving optimization problems. Artificial Intelligence Review, 1–31.

Liu, J., Liu, L., & Li, Y. (2019). A differential evolution flower pollination algorithm with dynamic switch probability. Chinese Journal of Electronics, 28(4), 737–747.

Luo, J., & Shi, B. (2019). A hybrid whale optimization algorithm based on modified differential evolution for global optimization problems. Applied Intelligence, 49(5), 1982–2000.

Marler, R. T., & Arora, J. S. (2004). Survey of multi-objective optimization methods for engineering. Structural and Multidisciplinary Optimization, 26(6), 369–395.

Martí, R., Resende, M. G. C., & Ribeiro, C. C. (2013). Multi-start methods for combinatorial optimization. European Journal of Operational Research, 226(1), 1–8.

Mirjalili, S. (2016). SCA: A Sine Cosine Algorithm for solving optimization problems. Knowledge-Based Systems, 96, 120–133.

Mirjalili, S., & Lewis, A. (2016). The Whale Optimization Algorithm. Advances in Engineering Software, 95, 51–67.

Mirjalili, S. M., Mirjalili, S. M., Lewis, A., Jangir, P., Saremi, S., Mirjalili, S. M., Coelho, L. D. S., Hatamlou, A., & Lewis, A. (2016). The Whale Optimization Algorithm. Advances in Engineering Software, 27(2), 46–61.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Mirjalili, S., Mirjalili, S. M., & Hatamlou, A. (2016). Multi-Verse Optimizer: a nature-inspired algorithm for global optimization. Neural Computing and Applications, 27(2), 495–513.

Mirjalili, S., Mirjalili, S. M., & Lewis, A. (2014). Grey Wolf Optimizer. Advances in Engineering Software, 69, 46–61.

Mishra, A., & Deb, S. (2019). Assembly sequence optimization using a flower pollination algorithm-based approach. Journal of Intelligent Manufacturing, 30(2), 461–482.

Mohanty, B. (2019). Hybrid flower pollination and pattern search algorithm optimized sliding mode controller for deregulated AGC system. Journal of Ambient Intelligence and Humanized Computing, 0123456789.

Nabil, E. (2016). A Modified Flower Pollination Algorithm for Global Optimization. Expert Systems with Applications, 57, 192–203.

Nakrani, S., & Tovey, C. (2004). On honey bees and dynamic server allocation in internet hosting centers. Adaptive Behavior, 12(3–4), 223–240.

Pan, J. S., Dao, T. K., Chu, S. C., & Nguyen, T. T. (2018). A novel hybrid GWO-FPA algorithm for optimization applications. Smart Innovation, Systems and Technologies, 86, 274–281.

Park, J. B., Lee, K. S., Shin, J. R., & Lee, K. Y. (2005). A particle swarm optimization for economic dispatch with nonsmooth cost functions. IEEE Transactions on Power Systems, 20(1), 34–42.

Porkodi, V., Singh, A. R., Sait, A. R. W., Shankar, K., Yang, E., Seo, C., & Joshi, G. P. (2020). Resource Provisioning for Cyber-Physical-Social System in Cloud-Fog-Edge Computing Using Optimal Flower Pollination Algorithm. IEEE Access, 8, 105311–105319.

Pradhan, A., Bisoy, S. K., & Das, A. (2021). A survey on PSO based meta-heuristic scheduling mechanism in cloud computing environment. Journal of King Saud University - Computer and Information Sciences, xxxx. https://doi.org/10.1016/j.jksuci.2021.01.003

Rastrigin, L. A. (1963). Convergence of random search method in extremal control of

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

multi-parameter systems. Avtomatika i Telemekhanika, 24, 1467–14731473.

Ratniyomchai, T., Oonsivilai, A., Pao-la-or, P., Kulworawanichpong, T., Huang, C. L., Jao, C. W., Zhang, X., Yeh, W. C., Ying Chung, V. Y., Wang, J., Yang, J., Jiang, Y. Z., Park, J. H. B., Lee, K. Y. K. S. K. Y., Shin, J. R., Lee, K. Y. K. S. K. Y., Bhattacharjee, K., Bhattacharya, A., Halder Nee Dey, S., … Abd Elazim, S. M. (2016). Preface. Studies in Computational Intelligence, 7(1),

Regalado, J. A., Emilio, B. E., & Cuevas, E. (2016). Optimal power flow solution using Modified Flower Pollination Algorithm. 2015 IEEE International Autumn Meeting on Power, Electronics and Computing, ROPEC 2015.

Saad, A. E. H., Dong, Z., & Karimi, M. (2017). A comparative study on recently-introduced nature-based global optimization methods in complex mechanical system design. Algorithms, 10(4).

Sakthivel, S., Manopriya, P., Venus, S., Ranjitha, S., & Subhashini, R. (2016). Optimal reactive power dispatch problem solved by using flower pollination algorithm. International Journal of Applied Engineering Research, 11(6), 4387–4391.

Schwefel, H. P. (1995). Evolution and Optimum Seeking. John Wiley & Sons.

Sidhu, M. M., & Mehta, S. (2017). Hybrid Gravitational Search Flower Pollination Algorithm for Combined Economic Emission Load Dispatch. International Research Journal of Engineering and Technology(IRJET), 4(7), 1485–1493.

Sinha, N., Chakrabarti, R., & Chattopadhyay, P. K. (2003). Evolutionary programming techniques for economic load dispatch. IEEE Transactions on Evolutionary Computation, 7(1), 83–94.

Sreenivasa Rao, M., Venkata Naresh Babu, A., & Venkaiah, N. (2018). Modified Flower Pollination Algorithm to Optimize WEDM parameters while Machining Inconel-690 alloy. Materials Today: Proceedings, 5(2), 7864–7872.

Sun, S., Cao, Z., Zhu, H., & Zhao, J. (2020). A Survey of Optimization Methods from a Machine Learning Perspective. *IEEE Transactions on Cybernetics*, *50*(8), 3668–3681.

Sun, Y., Peng, M., Zhou, Y., Huang, Y., & Mao, S. (2019). Application of Machine Learning in Wireless Networks: Key Techniques and Open Issues. *IEEE*

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Communications Surveys & Tutorials, *PP*(c), 1–1. https://doi.org/10.1109/comst.2019.2924243

Too, J., Abdullah, A. R., Saad, N. M., & Ali, N. M. (2018). Feature selection based on binary tree growth algorithm for the classification of myoelectric signals. *Machines*, *6*(4).

Umarani Srikanth, G., & Geetha, R. (2018). Task scheduling using Ant Colony Optimization in multicore architectures: a survey. *Soft Computing*, *22*(15), 5179–5196.

Valenzuela, L., Valdez, F., & Melin, P. (2017). Flower pollination algorithm with fuzzy approach for solving optimization problems. *Studies in Computational Intelligence*, *667*, 357–369.

Venter, G. (2010). Review of Optimization Techniques. *Encyclopedia of Aerospace Engineering*, 1–10.

Wahid, F., Ghazali, R., & Shah, H. (2018). An improved hybrid firefly algorithm for solving optimization problems. *Advances in Intelligent Systems and Computing*, *700*, 14–23.

Walters, D. C., & Sheble, G. B. (1993). Genetic algorithm solution of economic dispatch with valve point loading. *IEEE Transactions on Power Systems*, *8*(3), 1325–1332.

Wang, R., & Zhou, Y. (2014). Flower pollination algorithm with dimension by dimension improvement. *Mathematical Problems in Engineering*, *2014*.

Wang, Z., Luo, Q., & Zhou, Y. (2020). Hybrid metaheuristic algorithm using butterfly and flower pollination base on mutualism mechanism for global optimization problems. In *Engineering with Computers* (Issue 0123456789). Springer London.

Wierstra, D., Schaul, T., Peters, J., & Schmidhuber, J. (2008). Natural Evolution Strategies. *2008 IEEE Congress on Evolutionary Computation, CEC 2008*, *15*, 3381–3387.

Wong, W. K., & Ming, C. I. (2019). A Review on Metaheuristic Algorithms: Recent Trends, Benchmarking and Applications. *2019 7th International Conference on Smart Computing and Communications, ICSCC 2019*, 1–5.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Xue, B., Zhang, M., Browne, W. N., & Yao, X. (2016). A Survey on Evolutionary Computation Approaches to Feature Selection. *IEEE Transactions on Evolutionary Computation*, *20*(4), 606–626.

Yang, X.-S. (2010). Firefly algorithm, stochastic test functions and design optimisation. *ArXiv Preprint ArXiv:1003.1409*.

Yang, X.-S. (2015). *Recent Advances in Swarm Intelligence and Evolutionary Computation*. *April 2016*, 303.

Yang, X.-S., & Yang, X.-S. (2014). Chapter 6 – Differential Evolution. *Nature-Inspired Optimization Algorithms*, 89–97.

Yang, X., Karamanoglu, M., He, X., & Burroughs, T. (2016). *X . S . Yang , M . Karamanoglu , X . S . He , Flower Pollination Algorithm : A Novel Approach for Flower Pollination Algorithm : A Novel Approach for Multiobjective Optimization*. *00*(00), 1–17.

Yang, X. S. (2011). Metaheuristic optimization: Algorithm analysis and open problems. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *6630* , 21–32.

Yang, X. S. (2012). Flower pollination algorithm for global optimization. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *7445 LNCS*, 240–249.

Yang, X. S. (2014). Preface. *Studies in Computational Intelligence*, *585*, v–vi.

Yang, X. S., Karamanoglu, M., & He, X. (2013). Multi-objective flower algorithm for optimization. *Procedia Computer Science*, *18*, 861–868.

Yang, X. S., Karamanoglu, M., & He, X. (2014). Flower pollination algorithm: A novel approach for multiobjective optimization. *Engineering Optimization*, *46*(9), 1222–1237.

Yar, M. H., Rahmati, V., & Oskouei, H. R. D. (2016). A Survey on Evolutionary Computation: Methods and Their Applications in Engineering. *Modern Applied Science*, *10*(11), 131.

Yoo, H., Zavala, V. M., & Lee, J. H. (2021). A dynamic penalty function approach for

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

constraint-handling in reinforcement learning. *IFAC-PapersOnLine*, *54*(3), 487–491.

Yousri, D., Elaziz, M. A., & Mirjalili, S. (2020). Fractional-order calculus-based flower pollination algorithm with local search for global optimization and image segmentation. *Knowledge-Based Systems*, *197*, 105889.

Yu, C., Teo, K. L., Zhang, L., & Bai, Y. (2010). A new exact penalty function method for continuous inequality constrained optimization problems. *Journal of Industrial and Management Optimization*, *6*(4), 895–910.

Yu, J. J. Q., & Li, V. O. K. (2015). A social spider algorithm for global optimization. *Applied Soft Computing Journal*, *30*, 614–627.

Yu, N., & Qiu, D. (2017). The Karush-Kuhn-Tucker optimality conditions for the fuzzy optimization problems in the quotient space of fuzzy numbers. *Complexity*, *2017*.

Zawbaa, H. M., Hassanien, A. E., Emary, E., Yamany, W., & Parv, B. (2016). Hybrid flower pollination algorithm with rough sets for feature selection. *2015 11th International Computer Engineering Conference: Today Information Society What's Next?, ICENCO 2015*, 278–283.

Zhang, C., Liu, C., Zhang, X., & Almpanidis, G. (2017). An up-to-date comparison of state-of-the-art classification algorithms. *Expert Systems with Applications*, *82*, 128–150.

Zhang, W., Qu, Z., Zhang, K., Mao, W., Ma, Y., & Fan, X. (2017). A combined model based on CEEMDAN and modified flower pollination algorithm for wind speed forecasting. *Energy Conversion and Management*, *136*, 439–451.

Zhou, Y., & Wang, R. (2016). An Improved Flower Pollination Algorithm for Optimal Unmanned Undersea Vehicle Path Planning Problem. *International Journal of Pattern Recognition and Artificial Intelligence*, *30*(4), 1–27.

Zhou, Y., Wang, R., & Luo, Q. (2016). Elite opposition-based flower pollination algorithm. *Neurocomputing*, *188*, 294–310.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Zingg, D. W., Nemec, M., & Pulliam, T. H. (2008). A comparative evaluation of genetic and gradient-based algorithms applied to aerodynamic optimization. *European Journal of Computational Mechanics*, *17*(1–2), 103–126.

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