Firefly Algorithm: A Brief Review of the Expanding Literature

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Abstract Firefly algorithm (FA) was developed by Xin-She Yang in 2008 and it has become an important tool for solving the hardest optimization problems in almost all areas of optimization as well as engineering practice. The literature has expanded significantly in the last few years. Various FA variants have been developed to suit different applications. This chapter provides a brief review of this expanding and state-of-the-art literature on this dynamic and rapidly evolving domain of swarm intelligence.

Keywords Firefly algorithm · Discrete firefly algorithm · Nature-inspired algorithm · Scheduling · Combinatorial optimization · Engineering optimization

1 Introduction

Among swarm-intelligence-based algorithms, firefly algorithm (FA) is now one of the most widely used. Firefly algorithm was developed by Xin-She Yang in 2008 [1], based on inspiration from the natural behavior of tropical fireflies. FA tries to mimic the flashing pattern and attraction behaviour of fireflies. The purpose of these flash-

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ing lights are twofold: to attract mating partners and to warn potential predators. Obviously, these flashing light and its intensity can obey some rules, including physical laws. In essence, FA uses the following three idealized rules [1]:

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

As a firefly's attractiveness is proportional to the light intensity seen by adjacent fireflies, we can now define the variation of attractiveness β with the distance r by

$$\beta = \beta_0 e^{-\gamma r^2}, \tag{1}$$

where β_0 is the attractiveness at $r = 0$. The movement of a firefly i is attracted to another more attractive (brighter) firefly j is determined by

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

where the second term is due to the attraction. The third term is randomization with α being the randomization parameter, and ε_i^t is a vector of random numbers drawn from a Gaussian distribution at time t. Other studies also use the randomization ε_i^t can easily be extended to other distributions such as Lévy flights. It is worth pointing out that γ controls the scaling, while α controls the randomness. For the algorithm to convergence properly, randomness should be gradually reduced, and one way to achieve this is to use

$$\alpha = \alpha_0 \theta^t, \quad \theta \in (0, 1), \tag{3}$$

where t is the index of iterations/generations. Here α_0 is the initial randomness factor, and we can set $\alpha_0 = O(1)$ without losing generality.

Studies have shown that FA is very efficient [2–5]. Fister et al. provided a comprehensive review of the current literature of the firefly algorithm and its variants [6]. Since then, about 30 more journal papers published in the last a few months alone. In fact, a quick Google scholar search using firefly algorithm as the keyword returned 625 hits at the time of writing this chapter in July 2013. A similar search using Scirus gave 658 hits with 158 peer-reviewed journal papers. Therefore, it seems impossible to review every single piece of research work concerning firefly algorithms, however, it would be useful to summarize the key works/papers that we can get hold of and highlight the main and representative results.

Therefore, the main aim of this chapter is to briefly introduce the readers the state-of-the-art developments so as to provide classifications of variants, research works, and provide a good snapshot of the current literature. The rest of chapter

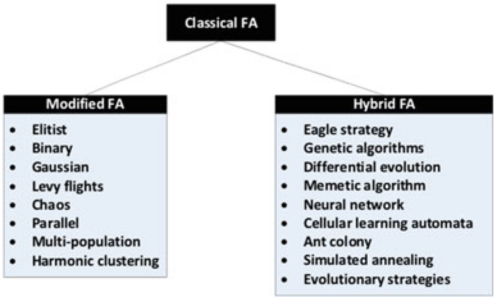

Fig. 1 Variants of the firefly algorithm

is organized as follows. In Sect. 2, a brief review of the modified and hybridized firefly algorithms is presented. Section 3 deals with the application domains where the firefly algorithms were successfully used, while Sect. 4 focuses on the application of the firefly algorithm in engineering optimization. Finally, conclusions are drawn briefly and the directions for future work are discussed in Sect. 5.

2 Classifications of Firefly Algorithms

The standard firefly algorithm has been proved very efficient and it has three key advantages

- Automatic subdivision of the whole population into subgroups so that each subgroup can swarm around a local mode. Among all the local modes, there exists the global optimality. Therefore, FA can deal with multimodal optimization naturally.
- FA has the novel attraction mechanism among its multiple agents, and this attraction can speed up the convergence. The attractiveness term is nonlinear, and thus may be richer in terms of dynamical characteristics.
- FA can include PSO, DE and SA as its special cases as shown in Chap. 1. Therefore, it is no surprise that FA can efficiently deal with a diverse range of optimization problems.

Many researchers use FA to solve a diverse range of problems, and they have also tried to develop various variants to suit for specific types of applications with improved efficiency. Using similar classification as proposed in [6], the variants of the firefly algorithm can be divided into modified and hybridized algorithms (Fig. 1). In total, there are more than 20 different FA variants.

The short review of research papers concerning the classical firefly algorithms can be summarized in Table 1.

Table 1 Classification of the firefly algorithms

Topic	References
The original firefly algorithm	[1]
Multi-modal test functions	[3]
Continuous and combinatorial optimization	[7]
Review of nature-inspired meta-heuristics	[8–10]

2.1 Modified FA

The modified firefly algorithms can be analyzed according to the setting of their algorithm-dependent parameters. In line with this, the firefly algorithms are classified according to the following criteria:

- representation of fireflies (binary, real-valued);
- population scheme (swarm, multi-swarm);
- evaluation of fitness function;
- determination of the best solution (non-elitism, elitism);
- randomization of moving the fireflies (uniform, Gaussian, Lévy flights, chaos distributions).

As a results, the existing studies concerning the modified algorithms can be presented in Table 2.

2.2 Hybrid Firefly Algorithms

The firefly algorithm has been designed as a global problem solver that should obtain the good results on the all classes of optimization problems. However, the No-Free-Launch theorem usually poses some limitations [42]. In order to overcome the limitations imposed by this theorem, hybrid methods tend to be used to develop new variants of nature-inspired algorithms including the variants of firefly algorithms. Various hybridizations have been applied on the firefly algorithm to seek improvements. Hybridization incorporates some problem-specific knowledge to the firefly algorithm. Normally, it was hybridized with other optimization algorithms, machine learning techniques, heuristics, etc. The short review of the major hybrid firefly algorithms is illustrated in Table 3.

3 Applications

Since its first appearance in 2008, in the last few years, the firefly algorithm has been used in almost every area of sciences and engineering, including optimization, classifications, travelling salesman problem, scheduling, image processing, and

Table 2 Modified firefly algorithms

Topic	References
Elitist firefly algorithm	[11]
Binary represented firefly algorithm	[12–16]
Gaussian randomized firefly algorithm	[17, 18]
Lévy flights randomized firefly algorithm	[4, 18, 19]
Chaos randomized firefly algorithm	[20–22]
Parallel firefly algorithm	[23, 24]
Multi-population	[25]
Harmonic clustering	[26, 27]
Quaternion firefly algorithm	[28]

Table 3 Hybrid firefly algorithms

Topic (with which the firefly algorithm hybridizes)	References
Eagle strategy using Lévy walk	[29]
Genetic algorithms	[15, 30]
Differential evolution	[31, 32]
Memetic algorithm	[33, 34]
Neural network	[35–37]
Cellular learning automata	[15, 38]
Ant colony	[39]
Simulated annealing	[40]
Evolutionary strategies	[41]

engineering designs. Some application domains are more theoretical, whilst others have focused on solving the real-world problems. The taxonomy of firefly algorithm applications can be seen in Fig. 2 where we have focused on three major areas of applications: optimization, classification and engineering designs.

3.1 Optimization

The firefly algorithm has been applied into the following classes of problems:

- continuous,
- combinatorial,
- constraint,
- multi-objective,
- multi-modal,
- dynamic and noisy.

Continuous optimization problems often concern a set of real numbers or functions, whilst in the combinatorial optimization problems, solutions are sought from a

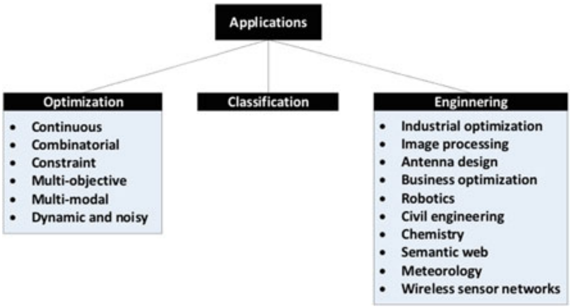

Fig. 2 Taxonomy of firefly algorithm applications

Table 4 Optimization applications

Topic	References
Continuous optimization	[2, 4, 7, 9, 18, 19, 46]
Combinatorial optimization	[47–55]
Constrained optimization	[56, 57]
Multi-objective optimization	[5, 58–63]
Multi-modal optimization	[64]
Dynamic and noisy environment	[65–69]

finite or infinite set, typically, of integers, sets, permutations, or graphs [43]. The latter class of optimization problems can also be called discrete optimization. Solutions of constrained problems must obey some limitations (also known as constraints). In the multi-objective problems, the quality of a solution is defined by its performance in relation to several, possibly conflicting, objectives. On the other hand, for multi-modal problems, there are a (large) number of local modes that are better than all their neighboring solutions, but do not have as good a fitness as the globally optimal solution [44]. The dynamic and noisy problems are non-stationary. That is, they change over time [45].

Various studies of the firefly algorithm in this application domain can be summarized in Table 4.

3.2 Classifications

Classification algorithms are procedures for selecting a hypothesis from a set of alternatives that best fits a set of observations or data. Usually, these algorithms are more relevant in machine learning, data mining, and neural networks. A review of existing studies from this area can be summarized as follows:

- The firefly algorithm was hybridized with the Rough Set Theory (RST) for finding a subset of features [70].
- The firefly algorithm was used for training the radial basis function (RBF) network [71].

Table 5 Engineering applications

Engineering area	References	Total
Industrial optimization	[73–94]	22
Image processing	[95–103]	9
Antenna design	[104–108]	5
Business optimization	[109–112]	4
Robotics	[113–115]	3
Civil engineering	[116, 117]	2
Chemistry	[118, 119]	2
Semantic web	[120]	1
Meteorology	[121]	1
Wireless sensor networks	[122]	1

- The firefly algorithm was used for clustering data objects into groups according to the values of their attributes [72].

4 Engineering Optimization

The firefly algorithm has become one of the most important tools for solving the design optimization problems in routine engineering practice. As can be seen from Table 5, almost every engineering domain has been covered by the applications of this algorithm. The majority of studies come from engineering and industries.

In summary, the rapid expansion of the research literature on the firefly algorithms in engineering optimization proves that the firefly algorithms enter in its matured phase. That is, after initial theoretical studies, more and more applications from real-world case studies have been emerged, which means that this algorithm has become a serious tool for solving various challenging real-world problems.

5 Conclusion

Though with a relative short history up to now, the firefly algorithm has become a matured optimization tool for solving a diverse of range of optimization problems such as engineering designs, scheduling, feature selection, travelling salesman problems, image processing, classifications and industrial applications. Over 20 new FA variants have been developed and new applications and studies are emerging almost daily.

The popularity of the firefly algorithm and its variants may be due to their simplicity, flexibility, versatility and superior efficiency. It is no surprise that FA has been used in almost every area of sciences, engineering and industry.

However, there is still room for improvements. Firstly, theoretical analysis is still very limited, and this is also true for many other nature-inspired algorithms. Mathematical analysis is challenging, but it is possible to use theories such as dynamical systems, Markov chains and statistics to gain insights into the working mechanisms of various variants. Secondly, more applications should focus on large-scale real-world applications. Thirdly, parameter tuning and parameter control can be a very useful area for further research. Finally, the current research communities strive to find better and smarter algorithms. It can be expected that the firefly algorithm and its variants may be extended and further developed into some sort of self-evolving and truly intelligent algorithms.

References

1. Yang, X. S.: Firefly algorithm (chapter 8). Nature-Inspired Metaheuristic Algorithms, pp. 79–90, Luniver Press, Cambridge (2008)
2. Gandomi, A.H., Yang, X.S., Alavi, A.H.: Mixed variable structural optimization using firefly algorithm. Comput. Struct. **89**(23–24), 2325–2336 (2011)
3. Yang, X. S.: Firefly algorithms for multimodal optimization. In: Proceeding of the Conference on Stochastic Algorithms: Foundations and Applications, pp. 169–178. Springer (2009)
4. Yang, X. S.: Firefly algorithm, levy flights and global optimization. In: Watanabe, O., Zeugmann, T. (eds.) Research and Development in Intelligent Systems XXVI, pp. 209–218. Springer, Berlin (2010)
5. Yang, X.S.: Multiobjective firefly algorithm for continuous optimization. Eng. Computers **29**, 175–184 (2013)
6. Fister, I, Fister, I.Jr., Yang, X.-S., Bret, J.: A comprehensive review of firefly algorithms. Swarm and Evolutionary Computation, http://dx.doi.org/10.1016/j.swevo.2013.06.001, (2013 In press)
7. Yang, X.S.: Firefly algorithm, stochastic test functions and design optimisation. Int. J. Bio-Inspired Comput. **2**(2), 78–84 (2010)
8. Parpinelli, R.S., Lopes, H.S.: New inspirations in swarm intelligence: a survey. Int. J. Bio-Inspired Comput. **3**(1), 1–16 (2011)
9. Yang, X.S.: Review of meta-heuristics and generalised evolutionary walk algorithm. Int. J. Bio-Inspired Comput. **3**(2), 77–84 (2011)
10. Zang, H., Zhang, S., Hapeshi, K.: A review of nature-inspired algorithms. J. Bionic Eng. **7**, 232–237 (2010)
11. Ong, H.C., Luleseged Tilahun, S.: Modified firefly algorithm. J. Appl. Math. **2012**, 12 (2012)
12. Chandrasekaran, K., Simon, S.P., Padhy, N.P.: Binary real coded firefly algorithm for solving unit commitment problem. Inf. Sci. (2013) http://dx.doi.org/10.1016/j.ins.2013.06.022
13. Chandrasekaran, K., Simon, S.P.: Network and reliability constrained unit commitment problem using binary real coded firefly algorithm. Int. J. Electr. Power Energy Syst. **43**(1), 921–932 (2012)
14. Falcon, R., Almeida, M., Nayak, A.: Fault identification with binary adaptive fireflies in parallel and distributed systems. In: Evolutionary Computation (CEC), 2011 IEEE Congress on, pp. 1359–1366. IEEE (2011)
15. Farahani, S.M., Abshouri, A.A., Nasiri, B., Meybodi, M.R.: Some hybrid models to improve firefly algorithm performance. Int. J. Artif. Intel. **8**(12), 97–117 (2012)
16. Palit, S., Sinha, S.N., Molla, M.A., Khanra, A., Kule, M.: A cryptanalytic attack on the knapsack cryptosystem using binary firefly algorithm. In: Computer and Communication Technology (ICCCT), 2011 2nd International Conference on, pp. 428–432. IEEE (2011)

17. Farahani, S.M., Abshouri, A.A., Nasiri, B., Meybodi, M.R.: A gaussian firefly algorithm. Int. J. Machine Learn. Comput. **1**(5), 448–454 (2011)
18. Yang, X.S.: Metaheuristic optimization: algorithm analysis and open problems. In: Pardalos, P.M., Rebennack, S. (eds.) Experimental Algorithms, pp. 21–32. Lecture notes in computer science, volume 6630Springer Verlag, Berlin (2011)
19. Yang, X.S.: Efficiency analysis of swarm intelligence and randomization techniques. J. Comput. Theor. Nanosci. **9**(2), 189–198 (2012)
20. dos Santos Coelho, L., de Andrade Bernert, D. L., Mariani, V. C.: A chaotic firefly algorithm applied to reliability-redundancy optimization. In: Evolutionary Computation (CEC), 2011 IEEE Congress on, vol. 18, pp. 89–98, IEEE (2013)
21. Gandomi, A.H., Yang, X.-S., Talatahari, S., Alavi, A.H.: Firefly algorithm with chaos. Commun. Nonlinear Sci. Numer. Simul. **18**(1), 89–98 (2013)
22. Yang, X.-S.: Chaos-enhanced firefly algorithm with automatic parameter tuning. Int. J. Swarm Intell. Res. **2**(4), 1–11 (2011)
23. Husselmann, A.V., Hawick, K.A.: Parallel parametric optimisation with firefly algorithms on graphical processing units. Technical, Report CSTN-141 (2012)
24. Subutic, M., Tuba, M., Stanarevic, N.: Parallelization of the firefly algorithm for unconstrained optimization problems. In: Latest Advances in Information Science and Applications, pp. 264–269 (2012)
25. Liu, G.: A multipopulation firefly algorithm for correlated data routing in underwater wireless sensor networks. Int. J. Distrib. Sens. Netw. (2013)
26. Adaniya, M.H.A.C., et al.: Anomaly detection using metaheuristic firefly harmonic clustering. J. Netw. **8**(1), 82–91 (2013)
27. Adaniya, M.H.A.C, Lima, F.M., Rodrigues, J.J.P.C., Abrao, T., Proenca, M.L.: Anomaly detection using dsns and firefly harmonic clustering algorithm. In: Communications (ICC), 2012 IEEE International Conference on, pp. 1183–1187. IEEE (2012)
28. Fister, I., Yang, X.-S., Brest, J., Fister, I.Jr.: Modified firefly algoirthm using quaternion representation. Expert Systems with Applications, http://dx.doi.org/10.1016/j.eswa.2013.06.070, (2013)
29. Yang, X. S., Deb, S.: Eagle strategy using levy walk and firefly algorithms for stochastic optimization. In: Nature Inspired Cooperative Strategies for Optimization (NICSO 2010), pp. 101–111 (2010)
30. Luthra, J., Pal, S.K.: A hybrid firefly algorithm using genetic operators for the cryptanalysis of a monoalphabetic substitution cipher. In: Information and Communication Technologies (WICT), 2011 World Congress on, pp. 202–206. IEEE (2011)
31. Abdullah, A., Deris, S., Mohamad, M., Hashim, S.: A new hybrid firefly algorithm for complex and nonlinear problem. In: Omatu, S., et al. (eds.) Distributed Computing and, Artificial Intelligence, vol. 151, pp. 673–680. Springer, Berlin (2012)
32. Abdullah, A., Deris, S., Anwar, S., Arjunan, S.N.V.: An evolutionary firefly algorithm for the estimation of nonlinear biological model parameters. PloS one. **8**(3), e56310 (2013)
33. Fister, I.Jr., Yang, X.-S., Fister, I., Brest, J.: Memetic firefly algorithm for combinatorial optimization. pp. 75–86. Jožef Stefan Institute (2012)
34. Srivastava, A., Chakrabarti, S., Das, S., Ghosh, S., Jayaraman, V.K.: Hybrid firefly based simultaneous gene selection and cancer classification using support vector machines and random forests. In; Proceedings of Seventh International Conference on Bio-Inspired Computing: Theories and Applications (BIC-TA 2012), pp. 485–494. Springer (2013)
35. Hassanzadeh, T., Faez, K., Seyfi, G.: A speech recognition system based on structure equivalent fuzzy neural network trained by firefly algorithm. In: Biomedical Engineering (ICoBE), 2012 International Conference on, pp. 63–67. IEEE (2012)
36. Nandy, S., Sarkar, P.P., Das, A.: Analysis of a nature inspired firefly algorithm based back-propagation neural network training. arXiv, preprint arXiv:1206.5360 (2012)
37. Ranjan Senapati, M., Dash, P.K.: Local linear wavelet neural network based breast tumor classification using firefly algorithm. Neural Comput. Appl. **30**, pp. 1–8 (2013)

38. Hassanzadeh, T., Meybodi, M.R.: A new hybrid algorithm based on firefly algorithm and cellular learning automata. In: 20th Iranian Conference on Electrical Engineering, pp. 628–633. IEEE (2012)
39. Aruchamy, R., Vasantha, K.D.D.: A comparative performance study on hybrid swarm model for micro array data. Int. J. Comput. Appl. **30**(6), 10–14 (2011)
40. Vahedi Nouri, B., Fattahi, P., Ramezanian, R.: Hybrid firefly-simulated annealing algorithm for the flow shop problem with learning effects and flexible maintenance activities. Int. J. Prod. Res. (ahead-of-print), 1–15 (2013)
41. Luleseged Tilahun, S., Ong, H.C.: Vector optimisation using fuzzy preference in evolutionary strategy based firefly algorithm. Int. J. Oper. Res. **16**(1), 81–95 (2013)
42. Wolpert, D.H., Macready, W.G.: No free lunch theorems for optimization. IEEE Trans. Evol. Comput. **1**(1), 67–82 (1997)
43. Papadimitriou, H., Steglitz, I.: Copmbinatorial Optimization: Algorithms and Complexity. Dover Publications, Inc., Mineola, NY (1998)
44. Eiben, A.E., Smith, J.E.: Introduction to Evolutionary Computing. Springer-Verlag, Berlin (2003)
45. Morrison, R.W.: Designing Evolutionary Algorithms for Dynamic Environments. Springer Verlag, Berlin (2004)
46. Poursalehi, N., Zolfaghari, A., Minuchehr, A., Moghaddam, H.K.: Continuous firefly algorithm applied to pwr core pattern enhancement. Nucl. Eng. Des. **258**, 107–115 (2013)
47. Durkota, K.: Implementation of a discrete firefly algorithm for the qap problem within the sage framework. Czech Technical University, Prague, Master's thesis (2009)
48. Hönig, U.: A firefly algorithm-based approach for scheduling task graphs in homogeneous systems. In: Informatics, pp. 24–33. ACTA Press (2010)
49. G. Jati. Evolutionary discrete firefly algorithm for travelling salesman problem. In: Adaptive and Intelligent Systems, pp. 393–403 (2011)
50. Khadwilard, A., Chansombat, S., Thepphakorn, T., Thapatsuwan, P., Chainate, W., Pongcharoen, P.: Application of firefly algorithm and its parameter setting for job shop scheduling. In: 1st Symposium on Hands-On Research and, Development, pp. 1–10 (2011)
51. Kwiecień, J., Filipowicz, B.: Firefly algorithm in optimization of queueing systems. Tech. Sci. **60**(2), 363–368 (2012)
52. Liu, C., Gao, Z., Zhao, W.: A new path planning method based on firefly algorithm. In: Computational Sciences and Optimization (CSO), 2012 Fifth International Joint Conference on, pp. 775–778. IEEE (2012)
53. Marichelvam, M.K., Prabaharan, T., Yang, X.-S.: A discrete firefly algorithm for the multi-objective hybrid flowshop scheduling problems. IEEE Trans. Evol. Comput. TEVC-00124-2012 (2012)
54. Sayadi, M.K., Ramezanian, R., Ghaffari-Nasab, N.: A discrete firefly meta-heuristic with local search for makespan minimization in permutation flow shop scheduling problems. Int. J. Industrial Eng. Comput. **1**(1), 1–10 (2010)
55. Wang, G., Guo, L., Duan, H., Liu, L., Wang, H.: A modified firefly algorithm for ucav path planning. Int. J. Hybrid Inf. Technol. **5**(3), 123–144 (2012)
56. Gomes, H.M.: A firefly metaheuristic structural size and shape optimisation with natural frequency constraints. Int. J. Metaheuristics **2**(1), 38–55 (2012)
57. Łukasik, S., Żak, S.: Firefly algorithm for continuous constrained optimization tasks. In: Computational Collective Intelligence. Semantic Web, Social Networks and Multiagent Systems, pp. 97–106. Springer, 2009.
58. Abedinia, O., Amjady, N., Naderi, M.S.: Multi-objective environmental/economic dispatch using firefly technique. In: Environment and Electrical Engineering (EEEIC), 2012 11th International Conference on, pp. 461–466. IEEE (2012)
59. Amiri, B.k, Hossain, L., Crawford, J.W., Wigand, R.T.: Community detection in complex networks: Multi-objective enhanced firefly algorithm. Knowl.-Based Syst. **46**, 1–11 (2013)
60. dos Santos Coelho, L., Bora, L.C.: Felipe Schauenburg, and Piergiorgio Alotto. A multiobjective firefly approach using beta probability distribution for electromagnetic optimization problems. IEEE Trans. Magn. **49**(5), 2085 (2013)

61. Poursalehi, N., Zolfaghari, A., Minuchehr, A.: Multi-objective loading pattern enhancement of pwr based on the discrete firefly algorithm. Ann. Nucl. Energy **57**, 151–163 (2013)
62. Niknam, T., Azizipanah-Abarghooee, R., Roosta, A., Amiri, B.: A new multi-objective reserve constrained combined heat and power dynamic economic emission dispatch. Energy **42**(1), 530–545. Elsevier (2012)
63. Santander-Jiménez, S., Vega-Rodríguez, M.A.: A multiobjective proposal based on the firefly algorithm for inferring phylogenies. In: Evolutionary Computation, Machine Learning and Data Mining in Bioinformatics, pp. 141–152. Springer (2013)
64. Miguel, L.F.F.: Rafael Holdorf Lopez, and Letícia Fleck Fadel Miguel. Multimodal size, shape, and topology optimisation of truss structures using the firefly algorithm. Adv. Eng. Softw. **56**, 23–37 (2013)
65. Abshouri, A.A., Meybodi, M.R., Bakhtiary, A.: New firefly algorithm based on multi swarm & learning automata in dynamic environments. In: IEEE proceedings, pp. 73–77 (2011)
66. Chai-Ead, N., Aungkulanon, P., Luangpaiboon, P.: Bees and firefly algorithms for noisy non-linear optimization problems. In: Proceedings of the International Multi Conference of Engineering and Computer Scientists **2**, 1–6 (2011)
67. Farahani, S.M., Nasiri, B., Meybodi. M.R.: A multiswarm based firefly algorithm in dynamic environments. In: Third International Conference on Signal Processing Systems (ICSPS2011), vol. 3, pp. 68–72 (2011)
68. Nasiri, B., Meybodi, M.R.: Speciation based firefly algorithm for optimization in dynamic environments. Int. J. Artif. Intell. **8**(12), 118–132 (2012)
69. Mustafa, M.W., Azmi, A., Aliman, O., Abdul Rahim, S.R.: Optimal allocation and sizing of distributed generation in distribution system via firefly algorithm. In: Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012 IEEE International, pp. 84–89. IEEE (2012)
70. Banati, H., Bajaj, M.: Firefly based feature selection approach. IJCSI Int. J. Comput. Sci. Issues **8**(4), 473–480 (2011)
71. Horng, M.H., Lee, Y.X., Lee, M.C., Liou, R.J.: Firefly meta-heuristic algorithm for training the radial basis function network for data classification and disease diagnosis. In: Parpinelli, R., Lopes, H.S. (eds.) Theory and New Applications of Swarm Intelligence, pp. 1–19. InTech, Rijeka (2012)
72. Senthilnath, J.: SN Omkar, and V. Mani. Clustering using firefly algorithm: Performance study. Swarm Evol. Comput. **1**(3), 164–171 (2011)
73. Abedinia, O., Amjady, N., Kiani, K., Shayanfar, H.A.: Fuzzy pid based on firefly algorithm: Load frequency control in deregulated environment. In: The 2012 International Conference on Bioinformatics and Computational Biology, pp. 1–7 (2012)
74. Apostolopoulos, T., Vlachos, A.: Application of the firefly algorithm for solving the economic emissions load dispatch problem. In: International Journal of Combinatorics, 2011, 23 p., (2011)
75. Aungkulanon, P., Chai-Ead, N., Luangpaiboon, P.: Simulated manufacturing process improvement via particle swarm optimisation and firefly algorithms. In Proceedings of the International MultiConference of Engineers and Computer Scientists **2**, 1–6 (2011)
76. Chandrasekaran, K., Simon, S.P.: Optimal deviation based firefly algorithm tuned fuzzy design for multi-objective ucp. IEEE Trans. Power Syst. **28**(1), 460–471 (2013)
77. handrasekaran, K., Simon, S.P.: Demand response scheduling in scuc problem for solar integrated thermal system using firefly algorithm. In: Renewable Power Generation (RPG 2011), IET Conference on, pp. 1–8. IET (2011)
78. Chatterjee, A., Mahanti, G.K., Chatterjee, A.: Design of a fully digital controlled reconfigurable switched beam concentric ring array antenna using firefly and particle swarm optimization algorithm. Prog. Electromagnet Res. B **36**, 113–131. EMW Publishing (2012)
79. dos Santos Coelho, L., Mariani, V.C.: Improved firefly algorithm approach for optimal chiller loading for energy conservation. Energy Buildings **59**, 1–320 (2012)
80. Dekhici, L., Borne, P., Khaled, B., et al.: Firefly algorithm for economic power dispatching with pollutants emission. Informatica Economică **16**(2), 45–57 (2012)

81. Dutta, R., Ganguli, R., Mani, V.: Exploring isospectral spring-mass systems with firefly algorithm. In: Proceedings of the Royal Society A: Mathematical, Physical and Engineering Science, vol. 467, pp. 3222–3240. The Royal Society (2011)
82. Hu, H.: Fa-based optimal strategy of trains energy saving with energy materials. Adv. Mater. Res. **485**, 93–96 (2012)
83. Kazemzadeh, A.S.: Optimum design of structures using an improved firefly algorithm. Int. J. Optim. Civ. Eng. **2**(1), 327–340 (2011)
84. Mauder, T., Sandera, C., Stetina, J., Seda, M.: Optimization of the quality of continuously cast steel slabs using the firefly algorithm. Materiali in tehnologije **45**(4), 347–350 (2011)
85. Mohammadi, s., Mozafari, B., Solimani, S., Niknam, T.: An adaptive modified firefly optimisation algorithm based on hong's point estimate method to optimal operation management in a microgrid with consideration of uncertainties. Energy (2013)
86. Bharathi Raja, S., Srinivas Pramod, C.V., Vamshee Krishna, K., Ragunathan, A., Vinesh, S., Optimization of electrical discharge machining parameters on hardened die steel using firefly algorithm. Engineering with Computers **36**, 1–9 (2013)
87. Rampriya, B., Mahadevan, K., Kannan, S.: Unit commitment in deregulated power system using Lagrangian firefly algorithm. In: Communication Control and Computing Technologies (ICCCCT), 2010 IEEE International Conference on, pp. 389–393. IEEE (2010)
88. Roeva, O.: Optimization of e. coli cultivation model parameters using firefly algorithm. Int. J. Bioautomation **16**, 23–32 (2012)
89. Roeva, O., Slavov, T.: Firefly algorithm tuning of pid controller for glucose concentration control during e. coli fed-batch cultivation process. In: Proceedings of the Federated Conference on Computer Science and Information Systems, pp. 455–462. IEEE (2012)
90. Rubio-Largo, Á., Vega-Rodríguez, M. A.: Routing low-speed traffic requests onto high-speed lightpaths by using a multiobjective firefly algorithm. In Applications of Evolutionary Computation, p. 12–21. Springer (2013)
91. Chandra Saikia, L., Kant Sahu, S.: Automatic generation control of a combined cycle gas turbine plant with classical controllers using firefly algorithm. Int. J. Electr. Power Energy Syst, **53**, 27–33 (2013)
92. Sanaei, P., Akbari, R., Zeighami, V., Shams, S.: Using firefly algorithm to solve resource constrained project scheduling problem. In: Proceedings of Seventh International Conference on Bio-Inspired Computing: Theories and Applications (BIC-TA 2012), pp. 417–428. Springer (2013)
93. Yang, X.S., Hosseini, S.S.S., Gandomi, A.H.: Firefly algorithm for solving non-convex economic dispatch problems with valve loading effect. Appl. Soft Comput. **12**(3), 1180–1186 (2011)
94. Yazdani, A., Jayabarathi, T., Ramesh, V., Raghunathan, T.: Combined heat and power economic dispatch problem using firefly algorithm. Front. Energy **7**, 1–7 (2013)
95. Hassanzadeh, T., Vojodi, H., Mahmoudi, F.: Non-linear grayscale image enhancement based on firefly algorithm. In: Swarm, Evolutionary, and Memetic Computing, pp. 174–181. Springer (2011)
96. Hassanzadeh, T., Vojodi, H., Moghadam, A.M.E.: An image segmentation approach based on maximum variance intra-cluster method and firefly algorithm. In: Natural Computation (ICNC), 2011 Seventh International Conference on, vol. 3, pp. 1817–1821. IEEE (2011)
97. Horng, M.H.: Vector quantization using the firefly algorithm for image compression. Expert Syst. Appl. **39**(1), 1078–1091 (2012)
98. Horng, M.H., Jiang, T.W.: The codebook design of image vector quantization based on the firefly algorithm. In: Computational Collective Intelligence. Technologies and Applications, pp. 438–447 (2010)
99. Horng, M.H., Jiang, T.W.: Multilevel image thresholding selection based on the firefly algorithm. In: Ubiquitous Intelligence and Computing and 7th International Conference on Autonomic and Trusted Computing (UIC/ATC), 2010 7th International Conference on, pp. 58–63. IEEE (2010)

100. Horng, M.H., Liou, R.J.: Multilevel minimum cross entropy threshold selection based on the firefly algorithm. Expert Syst. Appl. **38**(12), 14805–14811. Elsevier (2011)
101. Mohd Noor, M.H., Ahmad, A.R., Hussain, Z., Ahmad, K.A., Ainihayati, A.R.: Multilevel thresholding of gel electrophoresis images using firefly algorithm. In: Control System, Computing and Engineering (ICCSCE), 2011 IEEE International Conference on, pp. 18–21. IEEE (2011)
102. Xiaogang, D., Jianwu, D., Yangping, W., Xinguo, L., Sha, L.: An algorithm multi-resolution medical image registration based on firefly algorithm and powell. In: Intelligent System Design and Engineering Applications (ISDEA), 2013 Third International Conference, pp. 274–277. IEEE (2013)
103. Zhang, Y., Wu, L.: A novel method for rigid image registration based on firefly algorithm. Int. J. Res. Rev. Soft Intell. Comput. (IJRRSIC) **2**(2), 141–146 (2012)
104. Basu, B., Mahanti, G.K.: Firefly and artificial bees colony algorithm for synthesis of scanned and broadside linear array antenna. Prog. Electromagnet Res. B **32**, 169–190 (2011)
105. Basu, B., Mahanti, G.K.: Thinning of concentric two-ring circular array antenna using fire fly algorithm. Scientia Iranica, 19(6), 1802–1809 (2012)
106. Chatterjee, A., Mahanti, G.K.: Minimization in variations of different parameters in different φ planes of a small-size concentric ring array antenna using firefly algorithm. Ann. Telecommun. **68**, 1–8 (2012)
107. Sharaqa, A., Dib, N.: Circular antenna array synthesis using firefly algorithm. Int. J. RF Microwave Comput. Aided Eng. Article in press, Wiley Online Library (2013)
108. Zaman, M.A., Matin, A., et al.: Nonuniformly spaced linear antenna array design using firefly algorithm. Int. J. Microwave Sci. Technol. 2012, 8 (2012)
109. Banati, H., Bajaj, M.: Promoting products online using firefly algorithm. In: Intelligent Systems Design and Applications (ISDA), 2012 12th International Conference on, pp. 580–585, IEEE (2012)
110. Giannakouris, G., Vassiliadis, V., Dounias, G.: Experimental study on a hybrid nature-inspired algorithm for financial portfolio optimization. In: Artificial Intelligence: Theories, Models and Applications, pp. 101–111 (2010)
111. Salomie, I., Chifu, V.R., Pop, C.B., Suciu, R.: Firefly-based business process optimization. pp. 49–56 (2012), cited By (since 1996)
112. Yang, X. S., Deb, S., Fong, S.: Accelerated particle swarm optimization and support vector machine for business optimization and applications. In: Networked Digital Technologies, pp. 53–66 (2011)
113. Jakimovski, B., Meyer, B., Maehle, E.: Firefly flashing synchronization as inspiration for self-synchronization of walking robot gait patterns using a decentralized robot control architecture. Archit. Comput. Sys. ARCS 2010, 61–72 (2010)
114. Mardlijah, A.J., Widodo, B., Santoso, A.: A new combination method of firefly algorithm and t2fsmc for mobile inverted pendulum robot. J. Theor. Appl. Inf. Technol. **47**(2):824–831 (2013)
115. Severin, S., Rossmann, J.: A comparison of different metaheuristic algorithms for optimizing blended ptp movements for industrial robots. In: Intelligent Robotics and Applications, pp. 321–330 (2012)
116. Gholizadeh, S., Barati, H.: A comparative study of three metaheuristics for optimum design of trusses. Int. J. Optim. Civ. Eng. **3**, 423–441 (2012)
117. Talatahari, S., Gandomi, A.H., Yun, G.J.: Optimum design of tower structures using firefly algorithm. The Structural Design of Tall and Special Buildings (2012)
118. Fateen, S.E., Bonilla-Petriciolet, A., Rangaiah, G.P.: Evaluation of covariance matrix adaptation evolution strategy, shuffled complex evolution and firefly algorithms for phase stability, phase equilibrium and chemical equilibrium problems. Chem. Eng. Res. Des. **90**(12), 2051–2071 (2012)
119. Zhang, Y., Wang, S.: Solving two-dimensional hp model by firefly algorithm and simplified energy function. Mathematical Problems in Engineering. vol. 2013, 398141, 9 p (2013). doi:10.1155/2013/398141

120. Pop, C.B., Chifu, V.R., Salomie, I., Baico, R.B., Dinsoreanu, M., Copil, G.: A hybrid firefly-inspired approach for optimal semantic web service composition. Scal. Comput. Pract. Exp. vol. 12(3), pp. 363–369 (2011)
121. dos Santos, A.F., de Campos Velho, H.F., Luz, E.F.P., Freitas, S.R., Grell, G., Gan, M.A.: A Firefly optimization to determine the precipitation field on South, America. Inverse Prob. Sci. Eng. **21**, 417–428 (2013)
122. Breza, M., McCann, J.A.: Lessons in implementing bio-inspired algorithms on wireless sensor networks. In Adaptive Hardware and Systems, 2008. AHS'08. NASA/ESA Conference on, pp. 271–276. IEEE (2008)