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An enhanced firefly algorithm approach for solving a flexible job-shop scheduling problem

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Abstract

The Flexible Job Shop scheduling Problem has originated from the classical job shop scheduling problem. In FJSP an operation has the flexibility to be processed on any of the machine from a set of capable machines. Routing and scheduling are the two problems that make up the FJSP. Routing is the assigning of each operation to a machine out of a given set of eligible machines. Scheduling is the sequencing of all the assigned operations on the selected machines. The FJSP finds its importance in many research fields and can be applied to a large variety of real-world problems that can be modeled as a FJSP. They include simulation and optimization of transport systems, combinatorial optimization, scheduling in actual manufacturing systems etc. In this paper we propose an Improved Firefly algorithm to solve the FJSP. In this machine allocation and the problem of sequencing the operation are solved by developing a suitable conversion of the continuous functions. The functions such as attractiveness, distance, and movement are trans-formed into a form of new discrete functions. Different benchmark data taken from the literature are used to evaluate and compare the performance of proposed algorithm. The computational re-sults show that the developed Improved FFA gave better results than the other author's algorithm.

Keywords: flexible job sop scheduling, NP hard, firefly algorithm

1. Introduction

The problem of scheduling jobs on the machines has been quite famous amongst the researchers. The problems of scheduling jobs onto machines have been researched by number of scholars as this area further leads to the solution of number of other identical problems being faced in the industry. In practical manufacturing environment, there are always some uncertainties inducing unavailability of machines, such as unavailability of staff, operational errors of staff, machine breakdown, and so forth. The term scheduling refers to the action of allocating resources for a time to perform a collection of tasks. A schedule requires decision-making and plays a vital role in most manufacturing and production industries. Scheduling is considered as a major task for shop floor productivity improvement in a manufacturing industry. Li J. *et al*., proposed The purpose of scheduling in manufacturing is to minimize the manufacturing costs and time. This is achieved by finding out the time, of when to start manufacturing, which employees and labors to use, and which machines and equipment is to be used. There are some problems like machine failure, arrival of new job, maintenance activity, change in objective function etc. in manufacturing, transportations and engineering; hence, there is a requirement of scheduling in a real time system. The Scheduling is classified as Single Machine Scheduling, Flow Shop Scheduling, Job Shop Scheduling and Flexible Job Shop Scheduling. In this paper, we will emphasis on Flexible Job Shop Scheduling. The Firefly algorithm is used the behavior of fireflies can be formulate to model to solve scheduling problems. The flashing light of the fireflies build model into the objective function to obtain and hence makes it capable of solving optimization scheduling problems. The main objective of this dissertation is to study the Firefly algorithm for flexible job shop scheduling to enhance the firefly algorithm to evaluate and compare the performance of enhanced firefly algorithm with the existing system.

2. Literature Review

A) Hybrid particle swarm optimization and Tabu search algorithm for flexible job-shop scheduling problem

In this paper, the authors implemented a hybrid of particle swarm optimization (PSO) algorithm and Tabu search (TS) algorithm so as to solve the FJSP problem while taking into consideration that the maximum completion time (makespan) is minimized over the entire process. PSO provided with the swarm of high quality candidate solutions and TS is used to obtain an optimal solution in the neighborhood of the presented good solution. The results obtained show that the hybrid algorithm obtain better results than Genetic Algorithm, and is efficient and effective in order to solve for FJSP problems, even in higher scale based on the test results obtained.

B) An effective particle swarm optimization algorithm for flexible job-shop scheduling problem:

In this paper, the authors applied Particle Swarm Optimization algorithm so as to obtain the solution of FJSP problem with the aim to reduce the criteria of maximum completion time. The pro-posed method was tested on various data benchmarks available from the literature, such as Partial FJSP and Total FJSP.

C) An Improved Particle Swarm Optimization for Multi-objective Flexible Job-shop Scheduling Problem

In this paper, the author presented an improved version of PSO algorithm so as to solve the problem of multi-objective flexible job-shop scheduling. The basic feature of the improved version is that it incorporates the global search ability of PSO along with the superior approach to escape from the local optimum without any difficulty. In the initial part, the parameters of PSO are adjusted in-order to maintain a balance between the exploitation and exploration capabilities in an efficient manner. Furthermore while performing the search in PSO; a chaotic local optimizer is brought into consideration so as to increase the final precision and convergence rate.

D) New Hybrid Algorithm Based on Firefly Algorithm and Cellular Learning Automata

Here the authors proposed a new optimization model based on evolutionary techniques called as CLAFA. It combines one module called Cellular Learning Automata (CLA) and the Firefly Algorithm (FA). In the first part, the firefly algorithm is modified so as to increase its efficiency and it is then used with the CLA. In the modified algorithm proposed each dimension of the search space is assigned to one cell of cellular learning automata, and in each cell; the fireflies swarm are used to perform optimization of a particular dimension. The cellular learning automata are used to guarantee the diversity in the swarm of fireflies in each dimension, and adaptation of FA parameters in order maintain a state of equivalence among global and local search. The five benchmark functions such as Ackly, Rastrigin, Sphere, Xinshe yang and step function were analyzed for 10, 20 and 30 dimensions. The experimental results provide evidence that the method proposed is effective enough to find global optima and can further improve the global search and exploration rate of the firefly algorithm.

E) A Genetic Algorithm Approach for Solving a Flexible Job Shop Scheduling Problem

Most of the studies in this field has the main aim to reduce the total makespan of the job scheduling producing process. However in the paper listed here, the authors have proposed a mathematical model of the FJSSP problem. Some constraints are introduced so as to maximize the profit of the total scheduling job. Several factors such as fluctuating cost of raw materials, selling price and dissimilar demands have been taken into account to decrease the gaps between the model developed and the reality. Studies have been made on a manufacturer that produces several parts of gas valves. The scheduling problem for multi-part, multi-operation and multi-period with the use of parallel machines has been solved by using Genetic Algorithm.

F) A heuristic algorithm for solving flexible job shop scheduling problem

In this paper, the authors deal with the objective of reducing and minimizing the makespan in a flexible job scheduling problem using heuristic based approaches. A constructive approach is developed using simple and efficient heuristics so as to get good quality schedules in quick time. The heuristic algorithm developed makes use of accurate, flexible and a comprehensive criterion for job-scheduling process so as to create a feasible and a high-quality solution. The criterion takes into consideration several factors that affect the quality of solutions and each of the factors is assigned two weights. Using different values of weights leads to generation of different solutions/schedules. The algorithms has been tested and verified on benchmark instances present in the literature so as to evaluate its performance. Computational Results have shown that the heuristics proposed has obtained effective and efficient solutions in spite of being a simple algorithm. The time taken to obtain the effective schedules is very small, and can be compared to the meta-heuristics algorithm; and has shown promising results for practical domain problems

G) Assignment and Scheduling in Flexible Job-Shops by Hierarchical Optimization

In this paper, the authors put forward a hierarchical technique for flexible job-shop scheduling problem. They proposed a two phase algorithm so as to make the optimization process easier for the job-shop problem. The algorithm proposed is based on division of the problem into two sub categories: assignment sub problem and a sequencing sub problem. The method proposed pro-vides higher flexibility to a job-shop problem. The first sub problem is dealt with two methods: one is based on a heuristic approach using a local search, while the second one is a branch and bound algorithm. In order to evaluate the quality of assignment, a lower bound is kept along with it. The second sub-problem is handled using a hybrid genetic algorithm so as to properly handle sequencing problem. The algorithm takes into account all the numerous constraints and the necessities of the problem in hand. Numerous adapted operators are introduced and explored, which take into consideration of the two problems: Precedence constraints and Disjunctive Constraints. The simulation results show the proposed method is indeed successful in generating flexible, effective and efficient solution for the Flexible Job-shop problem.

3. Proposed Methodology of Firefly Algorithm to Solve Flexible Job Shop Scheduling

A. Problem Statements

A.1. To describe the firefly algorithm for flexible job-shop scheduling problem with limited resource constraints, we use the following convention. There are m number of machines and n number of jobs. For each job Ji ($1 \leq i \leq n$) there are ni sequence of operations. From the set of operations, an operation Oij (i=1,2,3,…..,n; j=1,2,3,….,ni) of job (Ji) can be processed by a machine mij from the set of available capable machines Mij. The processing time of the operation Oij on machine kϵMij is denoted by Pijk. It is not necessary that all the machines should be available at the starting time of the scheduling. The main role of scheduling is to find the starting time of each operation on a machine and to minimize the maximum processing time.

The main purpose of the FJSP with limited resource constraint is allotting operations to a machine and to schedule these job operations satisfying the following constraints:

1. The operation sequence for each job is defined in advance and the allotted sequence of operation must be followed strictly.
2. Only one operation can be processed by a machine at a time.
3. All the operations must be processed only on the assigned machine.
4. In this paper we consider makespan as the objective function to be minimized. Makespan (Cm) of the job is the total completion time of all the jobs.

A.2. Firefly Algorithm

The firefly algorithm just like particle swarm optimization algorithm is a nature inspired population based technique. It was developed by Xin-She yang. It is generally used for solving continuous optimization problems and that too of NP-hard nature. It is inspired by the way fireflies behave and interact socially. The flashing lights of the fireflies can be modeled into the objective function so as to obtain optimal solution and hence makes it capable of solving optimization problems. We consider the following assumptions for the firefly algorithm:-

1. The fireflies are unisex so that all the fireflies are attracted to each other regardless of their sex.
2. The attractiveness of the firefly is directly proportional to the brightness of the firefly and they both decreases with the distance. Therefore for any two glowing fireflies the less bright one will be attracted and move towards the brighter one. The fireflies move ran-domly if there are no brighter fireflies available.
3. The brightness of the firefly is determined by the objective function.

For maximization problems the brightness of the fireflies are proportional to the objective func-tion and for the minimization problems the brightness is inversely proportional to the objective function.

According to Yang, FA can very efficiently find global optimum values with high success rates. Previous literature and results have proven FA far better than other evolutionary algorithms like PSO and GA as far as efficiency and success rate is concerned. The difficulties faced in implementing this algorithm are to compute discrete distance between the fireflies and to model their coordinated movement.

B. Problem Formulation

B.1. The following notations are used in formulating the FJSP

i,h index of jobs, i,h =1,2,3,….,n

j,g index of operation sequence, j,g =1,2,3,…,ni

k index of machines, k=1,2,3,….,m

n total number of jobs

m total number of achiness

ni total number of operations of job i

Oij the jth operation of job i

Mij the set of available machines for the operation Oij¬

Pijk processing time of operation Oij on machine k

Tijk start time of operation Oij on machine k

Cij completion time of operation Oij

Ck is the completion time of Mk

Decision variables taken into account are:

$$X_{ijk} = \begin{cases} 1, \text{ if machine } k \text{ is selected for the operation} \\ 0, \text{ otherwise} \end{cases}$$

Min f_1 = m: (1)

Subject to :

$C_{ij} – C_{i(j-1)} \geq P_{ijk}X_{ijk}$, j= 2,…. …$n_i$; ∀i, j (2)

$[(C_{hg}-C_{ij}-t_{hjk})X_{hgk}X_{ijk}\geq 0] \vee [(C_{ij}-C_{hg}-t_{ijk})X_{hji}X_{ijk}\geq 0]$,

∀ (i, j), (h, g), k (3)

Equation (1) is to make sure that the makespan is minimized. Equation (2) is to make sure that the operation precedent constrained is maintained. Equation (3) is to check that only one operation is processed by each machine at a time when all the stated elements are satisfied by the first or the second constraint. Equation (4) depicts that one machine from the set of available capable machine could be selected for each operation.

The distance between any two flashing fireflies i and j, located at positions xi and xj, respectively, can be defined as Cartesian distance

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d}(x_{i,k}-x_{j,k})^2}$$

Where xi,k is the kth component of the spatial coordinate xi of the ith firefly, and d is the number of dimension.

The intensity with which the firefly glows is used to calculate the attractiveness of the firefly. The force with which each firefly attracts other fireflies is determined by their unique attractive-ness β.The attractiveness of the firefly can be formulated as follows. It is a monotonically de-creasing function:

$$\beta(r) = \beta_0 e^{-\gamma r^m}, (m \geq 1)$$

Where, r gives the distance between the two fireflies,β0 gives the attractiveness at r=0 and ɣ is the light absorption coefficient.

The firefly i move towards the more attractive (brighter) firefly j and it can be formulated as follows:

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha\left(rand - \frac{1}{2}\right)$$

Where the first term gives the current position of the firefly, the second term is the attractiveness and the third term is for randomization and α is the randomization parameter and rand is a random number generator in the range [0, 1].

C. Solution Implementation (Tools and Technology)

C.1. Hardware

The hardware details of the system on which the code was run and tested are as follows:

Processor Core: i5 processor (64 bit)

Random Access Memory: 4 GB

Hard Disk: 500 GB

Software: The Code was implemented using C++

Language using the Turbo C4 IDE on a system

Running 64 bit windows 7 Operating System.

Table 1

Processor	Core i5 processor (64 bit)
Random Access Memory	4 GB
Hard Disk	500 GB

C.2. The objective function is the goal we need to achieve, here the objective we need to achieve is to minimize the overall job completion time of all the jobs i.e. the makespan denoted by Cm.

C.3. The machine assignment array and the operation scheduling array are used to represent each solution or firefly. The permutation of these vectors is used to generate new fireflies in the population. To determine the objective function i.e. makespan, all the fireflies are evaluated. The intensity of the light of the nearby fireflies is associated with the objective function value of each fire-fly. The evaluation of the quality of the schedule is determined by the objective function value i.e. the makespan.

C.4. In this algorithm, the movement of the firefly is based on the light intensity and comparing the intensity between two fireflies. The brightness of the firefly is used to determine its attractive-ness and the brightness is associated with the objective function which is encoded. Therefore among any two fireflies the less bright firefly will move towards the brighter firefly. And if there is no brighter firefly then it will move randomly in the search space.

3. Result and Discussions

For testing our algorithm, three problem instances (problem 4x5, problem 8x8 and problem 10x10) are taken. Motaghedilarijani *et al*. [15, 32].

In order to conduct the experiment the proposed algorithm was implemented in c++ on an Intel core 2 duo processor with 1.5 GHz of clock speed and 2 GB RAM. We consider three practical data instances here in this experiment. Each data instances have the following parameters, number of jobs n, no of machines m and the no of operations ni. The performance comparison was done on the basis of average value taken from 20 different runs. The various parameters of the algorithm were initialized as follows: attractiveness of the fireflies i.e. $\beta 0$ =1.0, light absorption coefficient of the environment i.e. γ=0.1, and randomization parameter i.e. α=1.0. The number of iterations and the number of fireflies were taken as input by the user at the time of execution. We took the numbers as 50,20 respectively and incremented each by 10 for each run for 20 runs.

A. Problem 4x5

First of all we use a small scale instance shown in Table. 5.1 in order to test the optimizing ability and effectiveness of the proposed algorithm. The instance was taken from [32]. The average best value found by the proposed algorithm is shown below. Fig 5.1 shows the Gantt chart of the obtained results.

Table 2: Small scale instance 4x5.

Job	Position	Operation	M1	M2	M3	M4	M5
J1	1	O_{11}	2	5	4	1	2
	2	O_{12}	5	4	5	7	5
	3	O_{13}	4	5	5	4	5
J2	4	O_{21}	2	5	4	7	8
	5	O_{22}	5	6	9	8	5
	6	O_{23}	4	5	4	54	5
J3	7	O_{31}	9	8	6	7	9
	8	O_{32}	6	1	2	5	4
	9	O_{33}	2	5	4	2	4
	10	O_{34}	4	5	2	1	5
J4	11	O_{41}	1	5	2	4	12
	12	O_{42}	5	1	2	1	2

Best Schedule
A= 4 2 3 1 5 1 3 2 4 4 1 2
B= 7 1 2 8 9 4 3 10 11 5 12 6
Best time=11

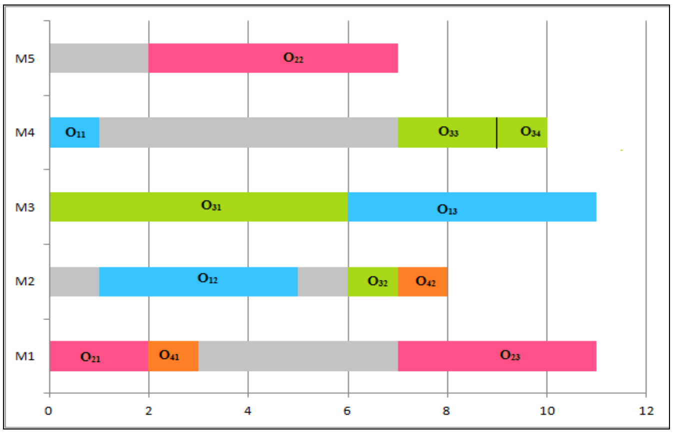

Fig 1: Gantt chart for the optimized schedule of the problem 4x5

B. Problem 8x8

Next, we apply the proposed algorithm on a medium scale instance shown in Table 5.2to test the optimizing ability and effectiveness of the proposed algorithm. The instance was taken from[32, 15]. The average best value found by the proposed algorithm is shown below.

Table 3

Job	Position	Operation	M 1	M 2	M 3	M 4	M 5	M 6	M 7	M 8
J1	1	O_{11}	5	3	5	3	3	0	10	9
	2	O_{12}	10	0	5	8	3	9	9	6
	3	O_{13}	0	10	0	5	6	2	4	5
J2	4	O_{21}	5	7	3	9	8	0	9	0
	5	O_{22}	0	8	5	2	6	7	10	9
	6	O_{23}	0	10	0	5	6	4	1	7
	7	O_{24}	10	8	9	6	4	7	0	0
J3	8	O_{31}	10	0	0	7	6	5	2	4
	9	O_{32}	0	10	6	4	8	9	10	0
	10	O_{33}	1	4	5	6	0	10	0	7
J4	11	O_{41}	3	1	6	5	9	7	8	4
	12	O_{42}	12	11	7	8	10	5	6	9
	13	O_{43}	4	6	2	10	3	9	5	7
J5	14	O_{51}	3	6	7	8	9	0	10	0
	15	O_{52}	10	0	7	4	9	8	6	0
	16	O_{53}	0	9	8	7	4	2	7	0
	17	O_{54}	11	9	0	6	7	5	3	6
J6	18	O_{61}	6	7	1	4	6	9	0	10
	19	O_{62}	11	0	9	9	9	7	6	4
	20	O_{63}	10	5	9	10	11	0	10	0
J7	21	O_{71}	5	4	2	6	7	0	10	0
	22	O_{72}	0	9	0	9	11	9	10	0
	23	O_{73}	0	8	9	3	8	6	0	10
J8	24	O_{81}	2	8	5	9	0	4	0	10
	25	O_{82}	7	4	7	8	9	0	10	0
	26	O_{83}	9	9	0	8	5	6	7	1
	27	O_{84}	9	0	3	7	1	5	8	0

Best Schedule
A= 2 5 6 3 4 7 5 7 4 1 2 6 3 1 4 6 7 3 8 2 3 8 4 1 2 8 5
B= 14 4 18 8 15 1 21 5 9 6 16 19 24 10 11 12 22 2 23 3 7
13 25 17 20 26 27
Best time=16

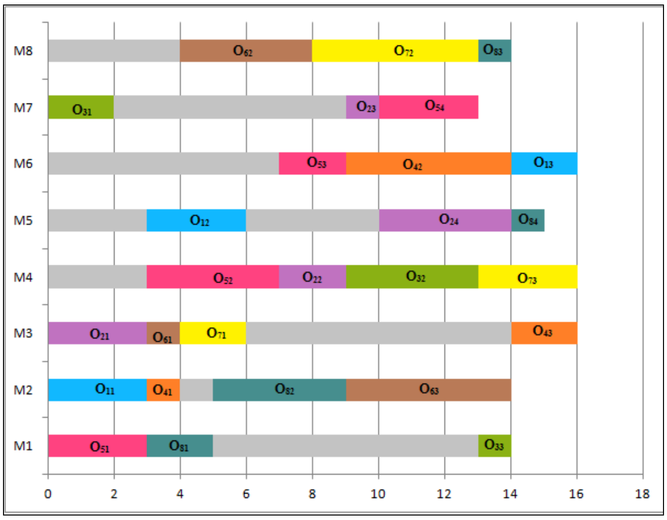

Fig 2: shows the Gantt chart of the obtained results.

The comparison results with other author's algorithm are shown in Table 5.4 and Table 5.5. The computational results suggest that the developed FFA is effective and efficient to solve the flexible job shop scheduling problem without any hybridization.

Table 4: Comparative result based on the Objective function (Make Span)

	TD	CGA	AL	AL+CGA	HPSO	FFA
4X5	11	13	12	16	11	11
8X8	19	15	16	15	16	15

Table 5: Comparative result based on execution time

	TD	CGA	AL	AL+CGA	HPSO	FFA
4X5	0.49	6.01	0.87	1.33	1.78	0.32
8X8	0.83	7.92	1.57	2.18	3.06	0.67

TD: - Temporal Decomposition
CGA: - Classic Genetic Algorithm
AL: - Approach by Localization
HPSO: - Hybrid particle Swarm Optimization
FFA: - Firefly Algorithm

4. Conclusion and future

In this paper, an effective Improved Firefly Algorithm is proposed for flexible job shop scheduling Problem with limited resource constraints. The Objective function that needs to be optimized is taken as makespan denoted by Cm. We developed discrete versions of the functions which are continuous, like movement, attractiveness and distance to update the position of the firefly in-stead of using the general firefly algorithm. The initial population was generated using a combination of rules. The performance of our algorithm is evaluated in comparison with the results obtained from other authors' algorithms for three representative instances. The computational results of our algorithm and the execution time taken by our approach were compared with the other authors approach. The results obtained and the time taken demonstrates the effectiveness of our approach. The future work is to enhance the convergence capability of the algorithm and to generalize the application of the proposed FFA for other combinatorial optimization problems

5. References

1. Abshouri. New Firefly Algorithm based On Multi swarm & Learning Automata in Dynamic Environments, 2011, 73-77
2. Agarwal S, Singh AP, Anand N, Evaluation performance study of Firefly algorithm, particle swarm optimization and artificial bee colony algorithm for non-linear mathematical op-timization functions, Fourth Int. Conf. Comput. Commun. Netw. Technol, 2013, 1-8,
3. Amico MD, Trubian M, Applying tabu search to the job-shop scheduling problem, Ann. Oper. Res, 1993; 41:231-252.
4. Arora S. Mutated Firefly Algorithm, 2014, 33-38.
5. Behnke D, Geiger M. Test Instances for the Flexible Job Shop Scheduling Problem with Work Centers, Opus.Unibw-Hamburg.De, 2012.
6. Bidar M, Rashidy Kanan H, Modified firefly algorithm using fuzzy tuned parameters, 13th Iran. Conf. Fuzzy Syst, 2013, 1-4,
7. Farahani SM, Abshouri AA, Nasiri B, Meybodi MR. Some hybrid models to im-prove firefly algorithm performance, Int. J. Artif. Intell. 2012; 8(12):97-117.
8. Fister XS. Yang J. Brest, A comprehensive review of firefly algorithms, Swarm Evol. Comput, 2013; 13:34-46.
9. Fister XS, Yang D, Fister. Cuckoo search: A brief literature review, Stud. Comput. Intell, 2014; 516:49-62.
10. Goel S, Panchal VK. Performance Evaluation of a New Modified Firefly Algo-rithm, 2014.
11. Gong Y, Zhang J, Author C, Small-World Particle Swarm Optimization, 2013, 25-31,
12. Hassanzadeh T, Meybodi MR. A new hybrid algorithm based on firefly algorithm and cellular learning automata, ICEE 2012 - 20th Iran. Conf. Electr. Eng, 2012, 628-633.
13. Ho NB, Tay JC. Solving multiple-objective flexible job shop problems by evolution and local search," IEEE Trans. Syst. Man Cybern. Part C Appl. Rev, 2008; 38(5):674-685.
14. Jia ZJZ, Chen HCH, Tang JTJ. An improved particle swarm optimization for multi-objective flexible job-shop scheduling problem, IEEE Int. Conf. Grey Syst. Intell. Serv, 2007, 1587-1592
15. Kacem S, Hammadi P, Borne, Pareto-optimality approach for flexible job-shop scheduling problems: Hybridization of evolutionary algorithms and fuzzy logic," Math. Comput. Simul., 2002; 60:3-5, 245–276,
16. Kennedy J. Small worlds and mega-minds: Effects of neighborhood topology on particle swarm performance, Proc. 1999 Congr. Evol. Comput. CEC 1999; 3:1931-1938, 1999.
17. Kennedy J. Neighborhood Topologies in Fully-Informed and Best-Of-Neighborhood Par-ticle Swarms, 1995.
18. Layeb Z. Benayad, a Novel Firefly Algorithm Based Ant Colony Optimization for Solving Combinatorial Optimization Problems, 2014; 11(2):19-37.
19. Li J, Pan Q, Xie S, Jia B, Wang Y. A Hybrid Particle Swarm Optimization and Ta-bu Search Algorithm for

Flexible Job-Shop Scheduling Problem," Int. J. Comput. Theory Eng., 2010; 2(2):189-194.
20. Liu Y, Tian Q, Zhang J, Yuan B. Xue, Adaptive firefly optimization algorithm based on stochastic inertia weight, Proc. - 6th Int. Symp. Comput. Intell. Des. Isc. 2013; 1(1):334-337.
21. Member JLI, Pan Q, Xie S, Li H, Jia B, Zhao C, An effective hybrid particle swarm optimization algorithm for flexible job-shop scheduling problem, Computing, 2009; 1: 8-13.
22. Pal K, Rai C, Singh AP, Comparative Study of Firefly Algorithm and Particle Swarm Optimization for Noisy Non-Linear Optimization Problems, Int. J. Intell. Syst. Appl. 2012; 4:50-57.
23. Pezzella F, Morganti G, Ciaschetti G, A genetic algorithm for the Flexible Job-shop Scheduling Problem, Comput. Oper. Res, 2008; 35:3202-3212.
24. Ponnambalam SG, Jawahar N, Girish BS, Ant A, Optimization C, Job F, An Ant Colony Optimization algorithm for Flexible Job shop scheduling problem," no. Pinedo, 2005.
25. Singh GP, Singh A, Comparative Study of Krill Herd, Firefly and Cuckoo Search Algorithms for Unimodal and Multimodal Optimization, Int. J. Intell. Syst. 2014; 6(3):35-49.
26. Tang J, Zhang G, Lin B, Zhang B. A hybrid algorithm for flexible job-shop schedul-ing problem," Procedia Eng, 2011; 15:3678-3683.
27. Tang R, Fong S, Deb S, Integrating Nature-inspired Optimization Algorithms to K-means Clustering, 2012, 116-123.
28. Tian Y, Gao W, Yan S, An improved inertia weight firefly optimization algorithm and application, Proc. - 2012 Int. Conf. Control Eng. Commun. Technol. ICCECT 2012, 64-68.
29. Vaghefinezhad S, Wong K. A Genetic Algorithm Approach for Solving a Flexible Job Shop Scheduling Problem," arXiv Prepr. arXiv1207.2253, 2012.
30. Yang S, Nw L, Intelligence C, International S, Cuckoo Search and Firefly Algo-rithm, 2014; 516:1-26.
31. Yang XS, He X. Firefly algorithm: recent advances and applications, Int. J. Swarm Intell. 2013; 1(1):36.
32. Motaghedi larijani K, Sabri-lahaie M, Heydari, Solving Flexible Job Shop Sche-duling with Multi Objective Approach, Int., 2010; 21(4):197-209.