

Solving Travelling Salesman Problem with a Hybrid Genetic Algorithm and Firefly Algorithm

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Abstract: The Problem of Travelling Salesman (TSP) is considered one of the most significant optimization problems. The problem is classified as NP-hard. A new, hybrid Firefly Algorithm (FA) and Genetic Algorithm (GA) strategy are brought together. The approach is implemented and tested on the TSP. Experiment results show that the hybrid approach produces a better route when compared to (FA and GA) for the same number of iterations.

Key words: Travelling Salesman Problem (TSP), Genetic Algorithm (GA), Firefly Algorithm (FA), hybrid approach, metaheuristics, swarm intelligence

INTRODUCTION

The Travelling Salesperson Problem (TSP) is a legendary and significant combinatorial optimization problem (Rego *et al.*, 2011). Given a directed graph of cities, weighted with the distances between these cities, the objective is to locate the shortest complete route (a sequence of visited nodes) between these cities including the return journey to the departure city. In the process, no city's name appear more than once. Finding the shortest route over a set of n cities requires the total comparisons of $(n-1)!$ permutation vectors (Matai *et al.*, 2010).

Providing a solution to the TSP is of a great importance, since, the solution to this problem can be applied to many other problems including communication networks and vehicle routing (Matai *et al.*, 2010; Diaby, 2010). TSP is classified as a hard problem which is the reason that researchers have attempted to apply different types of heuristic and meta heuristic methods to solve it. Meta heuristic refers to a computational method that iteratively tries to find the optimal solution by improving an applicant resolution with respect to a specific quality measure. Although, the solution provided by meta-heuristics is not guaranteed to achieve an optimal solution, it produces near optimal results (Rego *et al.*, 2011; Matai *et al.*, 2010).

The goal of TSP is to find a route between cities of different numbers, stopping at each city just once and return back to the point of departure while minimizing the

length of the journey. TSP appears to be a simple problem but it is among the most important classical optimization problems and it has proved difficult to solve conventionally (Diaby, 2010).

This research proposes a new hybrid approach to resolve the TSP. It contains a firefly algorithm in the first part and a Genetic algorithm in the second part, FA selects the initial answers of firefly. Then, GA is applied to conquer a superior solution in every single generation to get of the minimum journey length. The significance of the study relies on finding the shortest route over a set of n cities requires the total comparisons of $(n-1)!$ permutation. Finding a proper solution for the TSP is of great importance as it has many applications in vehicle routing and communication networks. On the other hand, TSP is NP-complete problem and finding a solution to the TSP indicates the ability to find solutions to other NP-complete problem. This research proposes a new hybrid approach to solve the TSP. the approach utilizes the swarm intelligence of the firefly algorithm to find initial solutions that will be employed by the Genetic algorithm to locate even better and enhanced solution.

Firefly algorithm is heuristic practices swarm optimization algorithm that stimulates the flashing activities of fireflies and the bioluminescent communication signals phenomenon that is applied for solving problems (Yang, 2009). Fireflies are beetles with wings that emit light and blinking at night (Yang, 2010). The flashlight is mainly used for attracting mates. In

addition, it is used as a mechanism of predictive warning to the fireflies about the probable predators. The firefly algorithm was framed by Yang (2009) and it became a significant implement for solving the hardest problems in most districts of combinatorial optimization (Ali *et al.*, 2014; Fister *et al.*, 2013; Tilahun *et al.*, 2017; Jaradat and Hamad, 2018).

Genetic Algorithms (GA) are computer procedures that stimulate the mechanics of life's natural evolution which include survival of the fittest, reproduction and mutation (Koza, 1994; Xie and Zhang, 2009). Due to being simple and widely applicable, GA have been successfully employed on a variation of hard problems in Science, Engineering and Business (Han and Kim, 2000; Khan *et al.*, 2016; Soylu and Uysal, 2017; Najafabadi and Mansouri, 2016).

The central aim of this research is to introduce a new hybrid Genetic-firefly approach for resolving Travelling Salesman Problem (TSP). The hybrid approach let the fireflies generate set of solutions which will be inserted into the Genetic algorithm to produce a better answer.

Literature review: TSP is a distinguished problem for locating an optimal route which can be addressed using variety of techniques. Numerous efforts have been devoted in developing algorithms for the challenging TSP. In this study, we will show some of them.

Recently, researchers have attempted to solve TSP, classified as NP complete by focusing on developing heuristic algorithms (Kennedy, 2011). In addition to the classical heuristic approaches using Genetic, ant colony, particle swarm and many more algorithms), new trends of mixing these algorithms to provide hybrid approaches for the purpose of enhancing the solution have been attempted. This section illustrates some of the methodologies that have been recognized for solving TSP.

Dwivedi *et al.* presented a scheme to find an improved solution to TSP by using a different crossover procedure for the Genetic algorithm that produces solutions of high quality to the problem of travelling salesman. Gharehchopogh *et al.* (2012) presented a hybrid Genetic-Ant Colony (ACO) approach. In this approach GA utilizes the routes that are created by applying ACO first. The GA produces better results in every generation. Through a presentation of the experimental results achieved, the researchers show that the hybrid approach produces better results when compared with GA or ACO alone.

Kumbharana and Pandey (2013) employed a Firefly (FA) heuristic approach to solve the problem. By making

some adjustments to the initial solution and the distance function, the researchers were able to extract solutions that are compatible with ACO and GA.

Hlaing and Khine (2011) applied an improved version of ACO to solve TSP by proposing a strategy of initial ants distribution. Their approach also updates the heuristic parameters dynamically. Hlaing uses the entropy value as a parameter that measures how much information is learned through the route. This parameter is constantly updated. The experimental results show enhancements in both speed and the concluding solution.

Nagpure and Raja (2012) proposed a hybrid approach that incorporate Artificial Bee Colony (ABC) with the Genetic Algorithm (GA). This approach was referred to as RBGCA. Here, the researchers applied the Genetic algorithm before each updating on the employee bee and after applying the scout bees. The approach claimed to provide results that are better than the results gained using the classical Genetic Algorithm (GA) alone.

Lin *et al.* (2016) presented a solution to the Travelling Salesman Problem (TSP) using a hybrid Genetic algorithm. The crossover operator in the proposed Genetic algorithm is enriched with a local search. The approach utilizes the local search crossover operator to enhance the quality of the optimum or sub-optimum answers. Comparative analysis proves that the hybrid Genetic algorithm beats other approaches in terms of the quality of the presented solution. However, the algorithm suffers computational complexity problems as it consumes a lot of time.

MATERIALS AND METHODS

In artificial intelligence and operations research, meta-heuristic approach have been widely used (Potvin, 1996; Yu *et al.*, 2013). Recently, many researchers have been focusing on mixing meta-heuristics to develop an optimization technique referred to as hybrid meta-heuristics (Lin *et al.*, 2016; Putri *et al.*, 2018).

This research proposes a new approach for solving TSP consisting of two phases: the first phase contains a firefly algorithm and the second contains a Genetic algorithm.

Firefly algorithm: The firefly algorithm is a meta-heuristic algorithm motivated by the act of blinking of fireflies (Yang, 2009). The main purpose of a firefly's flash is to attract other fireflies by sending signals through the action of blinking. Xin-she yang (Yang, 2010) framed the firefly algorithm through the following set of assumptions:

All fireflies are uni-sexual, this assumption indicates that all the fireflies can attract any individual firefly.

Attractiveness is relative to the intensity (apparent brightness), this assumption indicates that the brighter firefly is more attractive. Therefore, the firefly with less brightness will move toward the brighter one as a consequent action of attraction. Nevertheless, the intensity drops as their related distance increases. The firefly will move in a random manner, if there are brighter fireflies. The brightness and therefore, intensity is related to the objective function.

The firefly algorithm (Yang, 2010) is categorized as an algorithm of population-based nature. The algorithm constructs the global optimal of main objective by employing the intelligence of the swarm. In the firefly procedure, agents or fireflies are circulated randomly in the space of search. The firefly with the brighter radiance attracts other neighboring fireflies with less radiance. As the distance between fireflies increase, the attractiveness between them declines. If the firefly did not locate a brighter glowing one, it will move in a random manner (Yang, 2009). In this research, we employ a firefly algorithm due to having numerous significant benefits in solving hard problems.

Firefly is centered on brightness attractiveness. The brightness and therefore, the attraction decreases as the distance between the fireflies increases. This procedure results in the formation of subdivisions where fireflies in each division can crowd around local optimum among which the global solution can be located. The global communication among fireflies creates subgroups that circulate around local optimum. Therefore, fireflies are capable of simultaneously finding global and local optimal solutions.

Firefly is an efficient approach for solving NP-hard optimization problems. On the other hand, it is simple (as not much calculation) and can be easily implemented. In the formulation of the firefly methodology to TSP, the main objective is to minimize the weight summation of the edges in the tour that traverse each city exactly once. Having this objective in the beginning, the fireflies are scattered randomly through the search space. Basically, firefly algorithm involves the following two phases.

Variety of light intensity: Light intensity is correlated with the objective values (Yang, 2009, 2010). The high light intensity firefly will attract the low intensity one. Let us assume that there is a swarm of n fireflies and X_i denotes an answer for a firefly i while $F(X_i)$ represents the fitness value for X_i . Now, the brightness I of a firefly is designated to return its existing position X of its fitness value $F(X)$ (Yang, 2009):

$$I_i = F(X_i), 1 \leq i \leq n \quad (1)$$

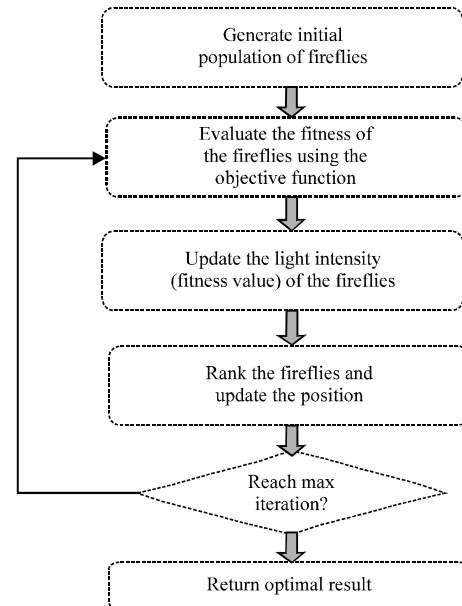


Fig. 1: Steps of the firefly algorithm

Movement in the direction of attractive firefly: The attractiveness of a firefly is corresponding to the intensity of the light produced by the firefly and seen by neighboring fireflies (Yang, 2009, 2010). Each firefly has its individual attractiveness parameter β which indicates attraction strength to other participants of the swarm. Nevertheless, the attractiveness β is not absolute as it will diverge with the distance r_{ij} between two fireflies i and j at respective positions X_i and X_j .

Next, we discuss the pseudo code of the firefly algorithm that was introduced by Yang (2010) to provide a more comprehensive explanation of the firefly optimization for the purpose of finding initial solution to TSP. Figure 1 summarizes the elementary steps of the firefly algorithm.

Data input and initialization: We are interested in identifying a tour of the cities $\{C_1, C_2, \dots, C_n\}$. The main objective is to find a single trip covering all cities with a shortest path return to the starting point. In order to accomplish this goal, the data set will be arranged in a graph. The representation of the graph is through an adjacency matrix A whose element A_{ij} is defined as:

$$\begin{cases} A_{ij} = w_{ij}, & \text{if } \exists L < i, j > \\ A_{ij} = \infty, & \text{if } \nexists L < i, j > \end{cases}$$

Create an initial population of fireflies $X_i (i = 1, 2, \dots, m)$ and import the array of dataset. Each firefly generates an

initial solution randomly. The initial value of the light intensity parameter I is initialized initial path length. Firefly i selects the next city to fly to its selection probability is associated with the light intensity and path lengths between cities. Firefly i will choose a shorter path and a city with higher intensity. The γ (Gamma) is the absorption coefficient and initially $\gamma = 1$. The distance between two positions is represented by the parameter r and r is calculated according to Eq. 2.

Light intensity and attractiveness: The light intensity I decreases when a firefly moves, so, its attractiveness will force to readjust. The best solution will be picked depending on the objective function which is minimum path length.

Attractiveness β value of a firefly is controlled by its brightness which in turn is affiliated with the prearranged objective function, light intensity declines with the distance from its source, varying with the distance r_{ij} between firefly i and firefly j . Moreover, light is immersed in the media.

Light intensity $I(r)$ diverges in consistent with the inverse square law $I(r) = I_s/r^2$ is the intensity at the source Eq. 2:

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

Distance and movement: The distance between any two fireflies i and j at x_i and x_j , respectively is the Cartesian distance:

$$r_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (3)$$

The fireflies will be ranked according to their fitness values and the one with the top fitness value will be nominated to take part in the next phase of the optimization procedure. The individual firefly fitness is considered as the path length of a single trip to all cities for each firefly:

$$\text{Fitness} = \text{path length}$$

where path length means the path length of the firefly's single trip to all cities. Then, for each firefly in the region will be attracted to another firefly with a brighter light. In situation of having equal brightness, the firefly will move in a random manner. The firefly adjusts its location using the existing location. The movement of a firefly i which is attracted to another much brighter (attractive) firefly j is determined by:

$$x_i = x_i + \beta_0 e^{-\gamma_0^2} (x_i - x_j) + \alpha \left(\text{rand} - \frac{1}{2} \right) \quad (4)$$

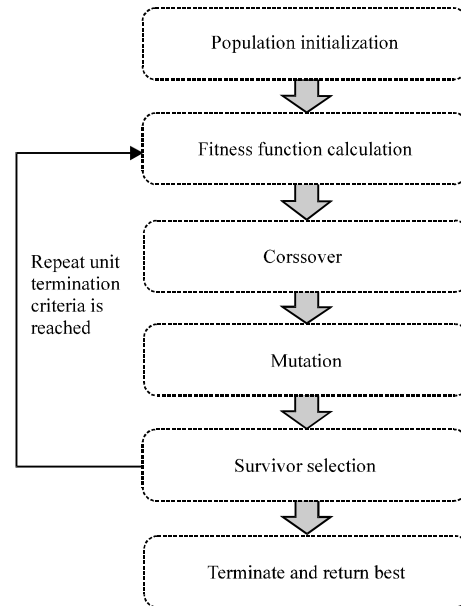


Fig. 2: Basic steps in Genetic algorithm

Genetic algorithm: Genetic Algorithm (GA) as a computational intelligence scheme is a search method used to find fairly accurate results for optimization problems (Koza, 1994). The idea is to maintain the population of applicant solution for the problem at hand and make it progress by iteratively submitting a set of stochastic operators. Figure 2 summarizes the basic steps of Genetic algorithm. The GA process consists of the following operations (Koza, 1994; Xie and Zhang, 2009).

Evaluation: The initial population is elected arbitrarily and the fitness of each individual in the population is computed that is the fitness is determined by how well the individual fits the problem and whether it is close to the optimum compared to the other individuals in the population.

Selection: Replicates the most successful solutions in the population depending on their fitness and remove the worst of them.

Crossover: Decomposes two distinctive solutions and then randomly blends their branches.

Mutation: Mutation takes place and some individuals are selected arbitrarily to be mutated and then a mutation point is chosen randomly.

Termination condition: We use a predetermined number of generations to ensure the solution will be achieved.

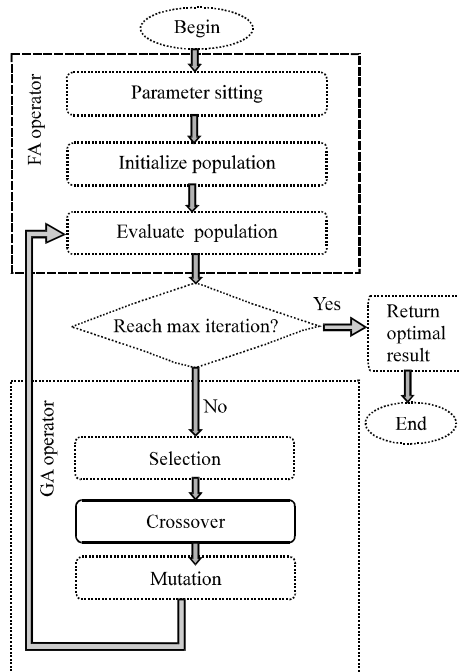


Fig. 3: The flow chart of hybrid Genetic with firefly algorithm

Proposed solution: In recent decades, many efforts have been made to find the best solution to TSP. One of these attempts has been by using hybrid algorithms. In this research, we are proposing a novel heuristic approach that combines Genetic algorithm with firefly algorithm to solve TSP. Figure 3 shows a flow chart of the hybrid approach. Next, we list the steps of the proposed algorithm.

In the hybrid algorithms, the initial responses generated by firefly are inserted into the Genetic algorithm. We use GA to reach a better answer in each generation. As a result, the GA is using the competent routes of firefly and each firefly in the search space moves toward the better one to generate the most efficient route. We have different parts of the answer in each iteration in the GA. All the solution space is searched in the hybrid method and therefore, there will be greater possibilities of generating a global solution. The general view of the hybrid algorithm is seen as a flow chart in Fig. 3. As the figure indicates, the algorithm has three fundamental perceptions: firefly, the GA and the stage of comparison of responses explained in the following section.

Adapting the algorithm for TSP: By referring to the integer linear programming formulation of the TSP (Diaby, 2010), the problem can be described as: given a finite set of N cities and a cost matrix $D = [d_{ij}]$. TSP aims to find the

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1. Parameter initialization.
 2. Scatter the fireflies randomly across the search space.
 3. Repeat until max generation reached
 - i. Evaluate the fitness of each firefly solution
 - ii. Update the intensity
 - iii. Rank the fireflies and update their positions.
 4. Initialize the chromosomes with the fireflies solutions.
 - i. Calculate Fitness for each chromosome, Selection, apply Crossover and Mutation.
 5. Repeat step 5 until termination criteria is reached.
 6. Output the best individual found.
 7. Compare (Best solution FA & GA).
 8. Output best solution
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Fig. 4: Psuedocode of the hybrid algorithm

optimal (minimum length) tour that visits each city exactly once and return to the starting city. The objective function of this TSP is defined in the following equation:

$$\text{minimise} \left(\sum_i \sum_j d_{ij} x_{ij} \right)$$

where, d_{ij} is the distance between vertices i and j and (x_{ij}) is the decision variable: $(x_{ij} = 1)$ when arc (i, j) is included in the tour and $(x_{ij} = 0)$, otherwise. The above equation states that the objective is to minimize the sum value of the distance in the valid tour.

The individual chromosome representing a feasible solution is encoded as a N dimensional integer vector $X_l = (X_{l1}, X_{l2}, \dots, X_{ln})$ where $(X_{l1}, X_{l2}, \dots, X_{ln})$ represent N consecutive city nodes in a complete valid tour with $l = 1, 2, 3, \dots, M$ (M is the population size).

The generating process of the initial population in the Genetic algorithm is the improved solution of the firefly algorithm. Each population contains a string of numbers that represent the city in the problem and the initial population is generated randomly. In this research we generate 20 populations (firefly) and define some parameters. The firefly algorithm finds the best solution and allows all others to move to it according to some equations, subsequently, sending these solutions to GA to undertake certain stochastic operations such as selection, crossover and mutation.

In the selection operation we select the best solutions depending on their fitness (minimum distances) to generate the child through the crossover operation which depends on a single point crossover. The swap mutation operation is then applied to the population. We compare the firefly results and the hybrid algorithm results. Figure 4 shows the pseudocode for the hybrid approach.

In the GA, a chromosome is a set of parameters that represent the solution to the problem which we try to solve. All the solutions are called the population. The chromosome is often represented as a binary string. In this study, chromosomes are represented as a string of numbers that represent each city in the TSP.

In most cases, the initial population is produced randomly, in this case, we generate the initial solution (Firefly) randomly in the FA and then define a set of parameters such as light Intensity I , initial attractiveness β_0 and light absorption coefficient γ . The light intensity in our research is represented by the total distance of the route. The firefly moves towards brighter one and so, its light intensity and its attractiveness decrease. The output from the FA is inserted into the GA and certain operations are undertaken.

These survival chromosomes with the best fitness value will have higher probabilities to be selected from the mating pool of the previous generation. In the selection operation in GA, the best solution is selected to represent the parents, depending on its fitness (shortest total distance) and the crossover operation is undertaken to generate the child. In the proposed solution, the crossover is a single point, the first part of the child generated by the first parent by selecting the departure and arrival cities randomly and the second part by the child generated by the other parent.

Mutation is a Genetic operator used to simulate the effect of errors that occur with low probability during duplication and is used to restore the information lost to the population. In mutation, the solution may change entirely from the previous solution. GA can come to a better solution by using mutation. In our research we implement the swap mutation and the position generated randomly. The resulting mutation rate in is 0.015.

RESULTS AND DISCUSSION

In this study, the hybrid FA-GA algorithm has been run to solve the travelling salesman problem using java eclipse on a platform with the specifications of Intel CORE i3 and 4GB RAM. The results of the proposed algorithm to solve TSP are shown. These results show significant improvement when the hybrid algorithm of the firefly algorithm and GA is used.

In firefly algorithm, parameters play a significant role (Yang, 2010) and an unsuitable parameter setting may lead to unfortunate results. The light absorption coefficient parameter γ that determines variation of light intensity with increasing distance from the communicated firefly is set to (1.0), the initial attractiveness parameter β is set to (0.2) and The random movement factor α is set initially to (0.4) and is dynamically tuned during the search process.

Table 1: Results comparison hybrid (ACO and GA) and hybrid (FA and GA)

Algorithms	Average solution	Best solution	Worst solution
Firefly	220	180	364
Genetic	260	180	340
Hybrid (ACO and GA)	384	340	368
Hybrid (FA and GA)	218	150	268

Table 2: Results comparison (No. of runs = 50)

Dataset names	FRI26	GR17	DANTZIG42	ATT48
Optimal solution	937	2085	699	10628
Hybrid algorithm	1271	2152	1455	71143

In Genetic algorithm, a chromosome is a set of parameters that represent the solution to the problem. The set of solutions are called the population. While the chromosome is often represented as a binary string in this problem, chromosomes are represented as a string of numbers that represent the city in TSP problem.

We compare the outputs of the GA, FA and hybrid algorithm using the matrix of distances between cities that was utilized by Gharehchopogh *et al.* (2012). Table 1 shows the comparison of four algorithms: the hybrid algorithm (firefly and Genetic), firefly, the Genetic algorithm and a hybrid algorithm (ACO and Genetic) (Gharehchopogh *et al.*, 2012) for solving TSP after each of them has been applied 10 times. As can be observed, the hybrid method using FA and GA has achieved a better solution in comparison to the three other algorithms used. In addition, the firefly and Genetic hybrid method is more efficient than ACO and Genetic hybrid when tested on the same dataset.

In addition, we tested the algorithm on a variety data set GR17 (17 cities), DANTZIG42 (42 cities), ATT48 (48 cities) and FRI26 (26 cities) datasets from the benchmark (Yu *et al.*, 2013) through 50 iterations in the hybrid algorithm. And subsequently, we compared our results with the optimal solution for each dataset and with the results of the firefly algorithm. Table 2 shows the comparison of results with different datasets.

CONCLUSION

This study has proposed a hybrid solution of firefly algorithm and Genetic algorithm for solving TSP. the proposed algorithm generates a list of solution by the firefly algorithm. Then, the Genetic algorithm enhances these solutions to generate better one. The experimental results show that a Hybrid Approach (FA and GA) provides better results than FA, GA and Hybrid Approach (ACO and GA) in most instances. The hybrid approach utilizes the global exploring ability of Genetic algorithm and the effectiveness of the firefly algorithm to achieve a reasonable final solutions along with an acceptable time.

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REFERENCES

- Ali, N., M.A. Othman, M.N. Husain and M.H. Misran, 2014. A review of firefly algorithm. *ARPN. J. Eng. Appl. Sci.*, 9: 1732-1736.
- Diaby, M., 2010. Linear Programming Formulation of the Multi-Depot Multiple Traveling Salesman Problem with Differentiated Travel Costs. In: *Traveling Salesman Problem, Theory and Applications*, Davendra, D. (Ed.). IntechOpen, London, England, UK., ISBN:978-953-307-426-9, pp: 257-282.
- Fister, I., X.S. Yang and J. Brest, 2013. A comprehensive review of firefly algorithms. *Swarm Evol. Comput.*, 13: 34-46.
- Gharehchopogh, F.S., I. Maleki and M. Farahmandian, 2012. New approach for solving dynamic traveling salesman problem with hybrid Genetic algorithms and ant colony optimization. *Int. J. Comput. Applic.*, 53: 39-44.
- Han, K.H. and J.H. Kim, 2000. Genetic quantum algorithm and its application to combinatorial optimization problem. *Proceedings of the 2000 Congress on Evolutionary Computation*, July 16-19, 2000, California, pp: 1354-1360.
- Hlaing, Z.C.S.S. and M.A. Khine, 2011. An ant colony optimization algorithm for solving traveling salesman problem. *Proc. Int. Conf. Inform. Communi. Manage.*, 16: 54-59.
- Jaradat, A.S. and S.B. Hamad, 2018. Community structure detection using firefly algorithm. *Intl. J. Appl. Metaheuristic Comput.*, 9: 52-70.
- Kennedy, J., 2011. Particle Swarm Optimization. In: *Encyclopedia of Machine Learning*, Sammut, C. and G.I. Webb, (Eds.). Springer, Berlin, Germany, ISBN:978-0-387-30768-8, pp: 760-766.
- Khan, S.U., I.M. Qureshi, A. Naveed, B. Shoaib and A. Basit, 2016. Detection of defective sensors in phased array using compressed sensing and hybrid Genetic algorithm. *J. Sens.*, 2016: 1-8.
- Koza, J.R., 1994. Genetic programming as a means for programming computers by natural selection. *Stat. Comput.*, 4: 87-112.
- Kumbharana, S.N. and G.M. Pandey, 2013. Solving travelling salesman problem using firefly algorithm. *Intl. J. Res. Sci. Adv. Technol.*, 2: 53-57.
- Lin, B., X. Sun and S. Salous, 2016. Solving travelling salesman problem with an improved hybrid Genetic algorithm. *J. Comput. Commun.*, 4: 98-106.
- Matai, R., S. Singh and M.L. Mittal, 2010. *Traveling Salesman Problem: An Overview of Applications, Formulations and Solution Approaches*. In: *Traveling Salesman Problem, Theory and Applications*, Davendra, D. (Ed.). InTech Publisher, Rijeka, Croatia, ISBN:978-953-307-426-9, pp: 1-24.
- Nagpure, H. and R. Raja, 2012. RBGCA-bee Genetic colony algorithm for travelling salesman problem. *Intl. J. Comput. Sci. Inf. Technol.*, 3: 5384-5389.
- Najafabadi, M.M. and S. Mansouri, 2016. Optimization of reliability coefficient of engineering systems using a specific model for Genetic algorithms. *J. Eng. Appl. Sci.*, 11: 119-124.
- Potvin, J.Y., 1996. Genetic algorithms for the traveling salesman problem. *Ann. Oper. Res.*, 63: 337-370.
- Putri, R.I., I. Mahmudi, M. Pujiatara, A. Priyadi and T. Taufik *et al.*, 2018. Modified firefly algorithm for improved maximum power extraction on wind energy conversion system. *Intl. J. Renewable Energy Res.*, 8: 1208-1216.
- Rani, K. and V. Kumar, 2014. Solving travelling salesman problem using Genetic algorithm based on heuristic crossover and mutation operator. *Intl. J. Res. Eng. Technol.*, 2: 27-34.
- Rego, C., D. Gamboa, F. Glover and C. Osterman, 2011. Traveling salesman problem heuristics: Leading methods, implementations and latest advances. *Eur. J. Oper. Res.*, 211: 427-441.
- Soylu, E. and A. Uysal, 2017. Hybrid Genetic-ant colony algorithm for travelling salesman problem. *Intl. J. Eng. Sci. Appl.*, 1: 86-90.
- Tilahun, S.L., J.M.T. Ngnotchouye and N.N. Hamadneh, 2017. Continuous versions of firefly algorithm: A review. *Artif. Intell. Rev.*, 1: 1-48.
- Xie, H. and M. Zhang, 2009. Sampling issues of tournament selection in Genetic programming. Master's Thesis, School of Engineering and Computer Science, Victoria University of Wellington, Kelburn, New Zealand.
- Yang, X.S., 2009. Firefly algorithms for multimodal optimization. *Proceedings of the 5th International Symposium, Stochastic Algorithms: Foundations and Applications 2009*, October 26-28, 2009, Sapporo, Japan, pp: 169-178.
- Yang, X.S., 2010. *Nature-Inspired Metaheuristic Algorithms*. 2nd Edn, Luniver Press, London, UK., ISBN:9781905986286, Pages: 148.
- Yu, S., S. Yang and S. Su, 2013. Self-adaptive step firefly algorithm. *J. Appl. Math.*, 2013: 1-8.