PERFORMATION EVALUATION OF BEE-ALGORITHM WITH NUMERICAL EXPERIMENTS

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ABSTRACT

Optimization is a search of perfection. There are many traditional & modern methods of optimization out of which modern methods are widely used due its convenience & efficiency where the inspiring tool is the act of natural bodies in optimizing their work. Swarm intelligence have become increasingly popular & are characterized by a decentralized way of working that mimics the behaviour of swarms. In present work natural foraging behavior of swarms of honey bee is studied & converted logically & mathematically in algorithm & validated using three test problems of two variables non-linear constrained taken from the literature & is compared with the conventional method & GA. The performance of present algorithm is close to the best optimal values of either conventional method or GA or even superior. Work is demonstrative however can be applied to innumerable optimization situation & there is need for further exploration in evaluating the performance to vary many different problems.

KEYWORDS: *Optimization, Modern method of optimization, Swarm-Intelligence, Bee-Behaviour, Bee-Algorithm, two variables non-linear constrained problems*

I. INTRODUCTION

Optimization is a search technique which is used to find out the best & optimum way from all possible ways. It is a search of perfection & is a key enabling tool for decision making. It has evolved from a methodology of academic interest into a technology that continues to significant impact in engineering research and practice. For these there are many methods of optimization which is broadly classified as Traditional method & Modern method. Problem of optimization is differ from process to process. Not a single traditional method is able to solve all type of optimization situations. There are drawbacks of traditional methods like choosing an algorithm which is based on the number of process parameters, nature of correlation between dependent & independent variables like linear, non linear, quadratic etc., number of equation of constraints & nature of constraints like linear, non linear, quadratic, equality, inequality etc. So deciding a method which fits into the given condition of problem is time consuming, risky,& difficult task. These all are lengthy, time consuming methods & a small error in calculation may divert the solution. Modern methods of optimization outcome over all these problems therefore are widely used due its convenience, easy handling & efficiency of result. The development of modern methods is inspired by the phenomenon of natural sciences. Swarm Intelligence[1],[2] is one of the modern method, is a field of computer science that designs and studies efficient computational methods for solving problems in a way that is inspired by the behaviour of real swarms. Principles of self-organization and local communication are important for understanding the complex collective behaviour. They are characterized by a decentralized way of working that mimics the behaviour of swarms of social insects, flocks of birds, or schools of fish. The ant colony optimization is based on the co-operative behaviour of ant colonies which are able to find the shortest path from their nest & food source. Particle Swarm Optimization is inspired by the behaviour of swarms of fishes or flocks of birds to find a good food place. The coordination of movements of the individuals in the swarm is the central aspect that inspires PSO Whereas Bee Algorithm mimics the food foraging behaviour of swarms of honey bees.

The group of honey-bee functioning as coherent wholes in which the members contribute harmoniously to the ultimate goal. The members of the group posses morphological, physiological & behavioural specializations that serve the efficient functioning of the colony. This posses group level adaption such as system of division of labour & feedback control, which evolved because they functioning & improve the efficiency of colony. The minimal model of forage selection that leads to the emergence of collective intelligence of honey bee swarms consists of three essential components: food sources, employed foragers and unemployed foragers. Food Sources are the source of nectar, Employed foragers are associated with a particular food source which they are currently exploiting & carry with them information about particular source, its distance and direction from the nest, the profitability of getting nectar from the source and share this information with Unemployed foragers. Unemployed foragers continually at look out for a food source to exploit. There are two types of unemployed foragers: scouts, searching the environment surrounding the nest for new food sources and onlookers waiting in the nest and establishing a food source through the information shared by employed foragers. The exchange of information among bees is the most important occurrence in the formation of the collective knowledge. The information is exchanged through dance among the bees in the hive. Dance is performed by a worker bee that has returned to the honey comb with nectar & hence recruit and direct other workers in gathering nectar.

The paper is presented in sections, starting with the introduction to modern methods of optimization with special reference to bee-algorithm. The next section takes a stock of the related papers published, followed by discussing the details of developed Bee-Algorithm. The accuracy of the developed Bee-Algorithm is validated & compared with conventional methods & GA in result & discussion section. The paper concludes with highlighting the findings of the present work & indicating the possible areas for further work that need to be explored.

II. LITERATURE SURVEY

In last few years foraging behaviour of honey-bee had been thoroughly studied by the biologists & scientists like Jerzy Paleolog [3] had studied about the Behavioural characteristics of honey bee(Apis mellifera) colonies containing mix of workers of divergent behavioural traits, where he compared the Defence behaviour, hygienic behavior, and syrup foraging rate of honey bee colonies artificially made up of defensive and gentle bees (1:1) with homogenous colonies made up only of either defensive or gentle bees. Baris Yuce, et.al. [4] developed Honey Bees Inspired Optimization Method: The Bees Algorithm ,the algorithm performs both an exploitative neighborhood search combined with random explorative search. L. Toth Amy et.al. [5] studied Evo-devo and the evolution of social behavior, A major goal in biology is to understand the evolution of complex traits, such as the development of multicellular body plans and animal social behavior. Studies of the evolution of development, or 'evo-devo', have greatly improved our understanding of morphological evolution in animals**.** G.M Bianco [6] presented a mapping paradigm for large scale precise navigation that takes inspiration from the bees' large scale navigation behaviour. Bees performed very long navigations when they feed, travelling for many kilometres but, at the same time, getting an excellent precision when they return to their small hives. H.F Wedde et al. [7] introduced a fault-tolerant, adaptive and robust routing protocol inspired from dance language and foraging behaviour of honey bees for routing in telecommunication network, called BeeHive. C.S.Chong et al. [8] presented a novel approach that uses the honey bees foraging model to solve the job shop scheduling problem. S. Nakrani and Tovey [9] proposed a honey bee algorithm for dynamic allocation of internet services. T. Schmickl et al. [10] evaluate the robustness of bees' foraging behaviour by using a multiagent simulation platform. They investigate how the time-pattern of environmental fluctuations affects the foraging strategy and the efficiency of the foraging. They conclude that the collective foraging strategy of a honeybee colony is robust and adaptive, and that its emergent features allow the colony to find optimal solutions. Y. Yonezawa and Kikuchi [11] examine the foraging behaviour of honey bees and construct an algorithm to indicate the importance of group intelligence principals. The algorithm is simulated with one and three foraging bees and the computational simulation results showed that three foraging bees are faster than the system with one foraging bee at decision making process. They also indicate that the honey bees have an adaptive foraging behaviour at complex environment.

III. METHODOLOGY

The aim of present work are:

i. Collection of information from books & journals
ii. Understanding the methodology , principles & algorithm
iii. Study of application of Bee- algorithm with case study
iv. Developing flowchart
v. Developing algorithm
vi. Developing software code in VB6

The work is practically divided in two parts

i. Developing algorithm & source code
ii. Validation of source code with the reported optimization problem & comparison of solution obtained with the conventional method.

3.1 present work part 1

The motivation of Bee- algorithm is in behaviour of honey bees, the gathering & processing of information collectively in foraging process. Inspiring from these natural Bee-Behaviour of foraging, Bee-Algorithm has been developed that adopted the steps followed on foraging behaviour. The behaviour of natural bees in foraging process is logically converted & adopted in Bee-Algorithm. The converted & equivalent steps adopted in Bee-Algorithm with respect to Bee-Behaviour are given in table 1.

Table1: The equivalent steps of Bee-Behaviour & Bee-Algorithm.

Sr. No.	BEE-BEHAVIOUR	BEE-ALGORITHM
1	Choosing among food sources	i. Division of limits ii. Generation of random numbers between search zone of 120^0
2	Gathering the information obtained by foragers	i. Various combination of search zone ii. Calculating the function value by using search zone numbers iii. Gathering the function value from all direction
3	Adjusting selectivity in relation to forage abundance	i. Comparing the function value ii. Adjusting the selectivity either in terms of minimizing or maximizing
4	Adjusting nectar-processing rate wrt nectar-collecting rate	i. Repeating the steps for best values

The flowchart developed for Bee-Algorithm are shown in figure1.

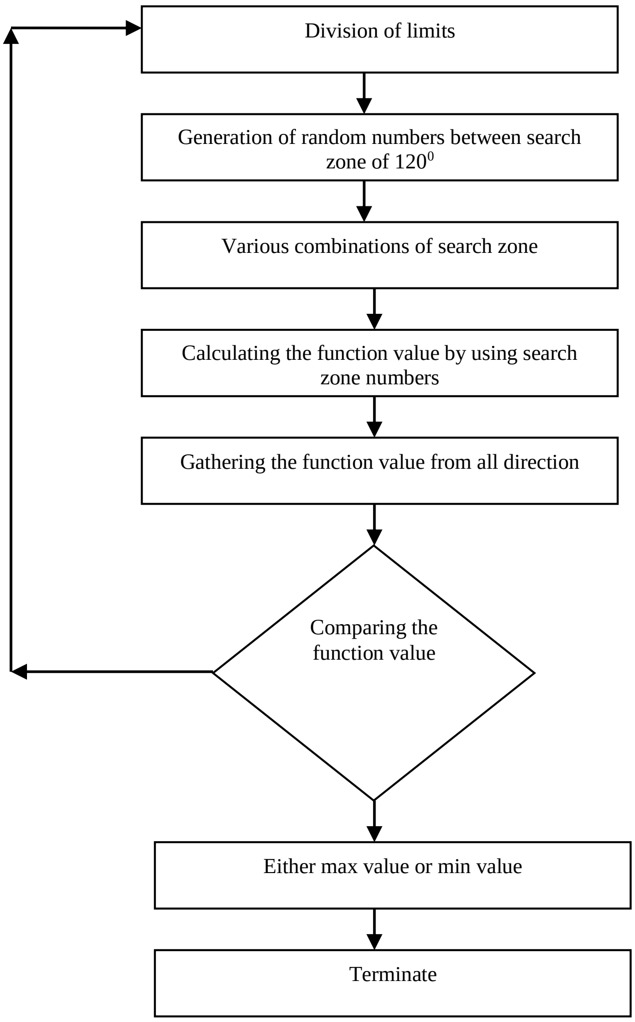

Figure1: Flowchart of developed Bee-Algorithm

The steps of natural foraging behaviour of honey bees are logically & mathematically converted in developing the Bee- Algorithm. The details of basic steps are as follows

i. Division of limits

Inspiring by the natural behaviour of bees in choosing the food sources from the surrounding, in developed bee- algorithm unknown variable say x or y; is chosen from the given limits that are able to give optimum value of given function. Just like for natural bees surrounding is nothing but the whole universe & bees search their food source in this surrounding in random direction, similarly in developed bee algorithm the term surrounding is the space between the given limits i.e. the value from the lower limit & the upper limit of the variable. This surrounding is of 360^{o} . the 360^{o} surrounding space is then divided into search zone of 120^{o} where the artificial bees are allowed to search the optimum value of variables.

ii. Generation of random numbers between search zone of 120o

In natural process certain number of foragers went in search of food source similarly 10 artificial bees went in the search zone & searched & picked 10 random numbers from the search zone limits.

iii. Various combination of search zone

The search zone distribution is done for both variable x & y thus in total there are 6 search zones, 3 for variable x (x1,x2,x3) & 3 for variable y(y1,y2,y3). Combinations of these search zones are obtained & thus there are 9combinations of search zones, they are:

1) x1y1
2) x1y2
3) x1y3
4) x2y1
5) x2y2
6) x2y3
7) x3y1
8) x3y2
9) x3y3

iv. Calculating the function value by using search zone numbers

Random numbers generated in each search zone is substituted in given function according to the combinations of search zone, & function value is calculated.

v. Gathering the function value from all direction

Function value from all the search zone is gathered. Here search zone is the direction of source & the numbers in these direction denotes the distance from the origin.

vi. Comparing the function value

The gathered function value is then compared according to the criteria of minimizing or maximizing the function. The optimum value of variables x & y is reported in terms of direction & distance.

vii. Adjusting the selectivity either in terms of minimizing or maximizing

Selection of the optimum number is done on the basis of the minimizing or maximizing the function.

viii. Repeating steps for best optimum values

Repeating the steps for obtaining the best possible optimum values.

These logically converted steps is then mathematically converted & coded in programmable language of VB6. The program is made for two variables non-linear optimization problem. Figure 2 show the **S**napshot of Bee-Algorithm software .

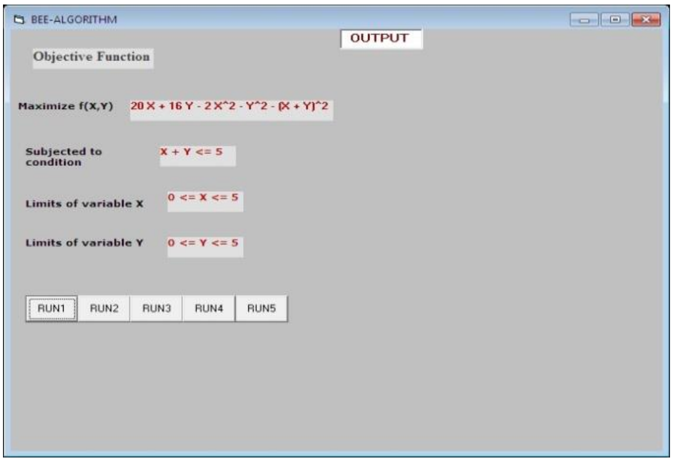

Figure2: Snapshot of Bee-Algorithm software

3.2 present work part 2

This part is devoted for validation of source code & performance comparison with the conventional methods. It is done by taking the problems of optimization from the literature. The optimum answer obtained from the developed bee-algorithm is compared with those reported in literature.

Numerical experiments

Test problem 1:

Objective Function:

Maximize $f(X,Y) = 20X + 16Y - 2X^2 - Y - (X + Y)^2$

Subject to $X+Y \leq 5$

$0 \leq X \leq 5$

$0 \leq Y \leq 5$

Conventional technique

The objective function can be solved using Penalty function method that includes approximation of linear programming. The details are reported in literature [12].

Bee-Algorithm technique

By using bee-algorithm maximum function value is obtained in 5th iteration of 2nd run

Maximum function value = 46.33225

Optimum value of x = 2.352352

Optimum value of y = 2.647648

The details of the comparison of the best values obtained in five consecutive runs are given in table 2

Table2: Comparison of the best values obtained in five consecutive runs for eq.1

Sr.No.	Run No.	Max f(X,Y)	Best value of Max f(X,Y)
1	1	46.14938	**46.33154**
2	2	45.00468	
3	3	46.3187	
4	4	45.95835	
5	5	**46.33154**	

The details of zone wise best values comparison are given in table 3

Table3: the details of zone wise best values comparison for run 5 of eq.1

Details of 5th run						
X zone	**X position**	**X value**	**Y zone**	**Y position**	**Y value**	**Function value**
X2	**10**	**2.308999**	**Y2**	**10**	**2.691001**	**46.33156**
X3	9	3.037517	Y2	9	2.12291	45.12713
X2	9	2.87709	Y3	9	1.962483	45.11343
X3	9	3.037517	Y3	9	1.962483	44.84571
X2	8	1.312604	Y1	8	4.020922	42.52666
X1	8	0.9790779	Y1	8	4.020922	40.83131
X1	8	0.9790779	Y2	8	1.785249	35.39974
X3	3	3.214751	Y1	3	4.646527	34.5803
X1	3	0.3534727	Y3	3	1.785249	27.62231

Comparison of optimum results obtained by using penalty function method and Bee-Algorithm are shown in table 4

Table4: the Comparison of optimum results obtained by using penalty function method and Bee-Algorithm

Maximum value of function	Penalty function method	Bee-Algorithm
F(X, Y)	**46.333**	**46.33154**
X	2.333	2.357827
Y	2.666	2.642173

Figure 3show the **S**napshot of Bee-Algorithm software in run mode for equation 1

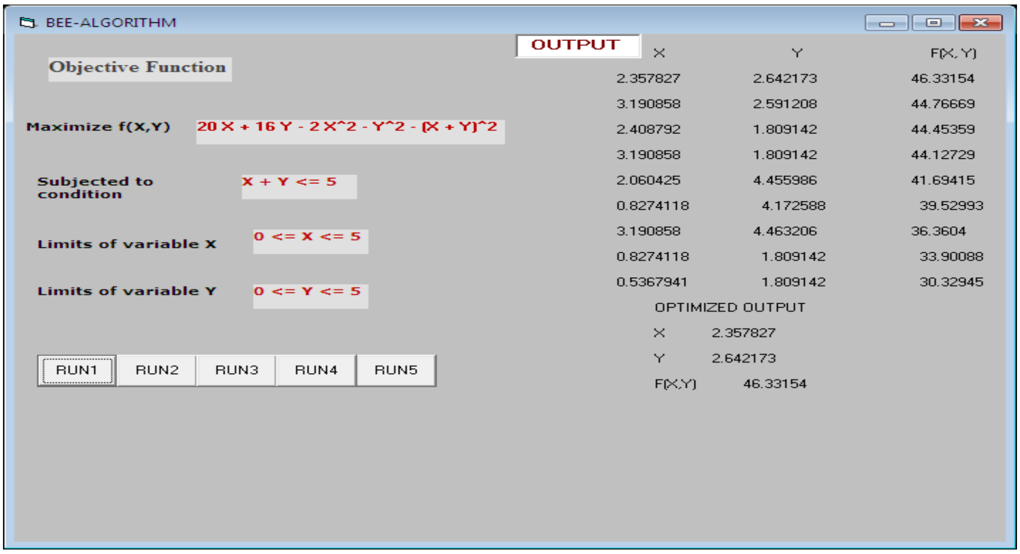

Figure 3: Snapshot of Bee-Algorithm software in run mode for equation 1

Test problem 2

Objective Function

Maximize $f(X,Y) = 5X - Y^2 + 8Y - 2Y^2$

Subject to $3X + 2Y \leq 6$

$0 \leq X \leq 2$

$0 \leq Y \leq 3$

Conventional technique

The objective function has been solved by Frank-Wolfe algorithm. The details are reported in the literature[12].

The details of the comparison of the best values obtained in five consecutive runs are given in table 5

Table5: The comparison of the best values obtained in five consecutive runs for eq.2

Sr.No.	Run No.	Max f(X,Y)	Best value of Max f(X,Y)
1	1	10.19977	**10.27327**
2	2	9.929936	
3	3	**10.27327**	
4	4	9.797823	
5	5	9.53897	

The details of zone wise best values comparison are given in table 6

Table 6: The details of zone wise best values comparison for run 3 of eq.2

Details of 3^{th} run						
X zone	**X position**	**X value**	**Y zone**	**Y position**	**Y value**	**Function value**
X2	**1**	**0.9917915**	**Y2**	**1**	**1.412968**	**10.27327**
X2	1	0.9917915	Y1	6	0.9229546	9.787059
X1	10	0.6578691	Y2	1	1.412968	8.603654
X1	8	0.559182	Y1	8	0.8262255	7.357769
X3	1	0	Y2	1	1.412968	5.314308
X2	1	0.9917915	Y3	1	0	4.958958
X3	6	0	Y1	6	0.9229546	4.828101
X1	4	0.6558627	Y3	4	0	3.279314
X3	1	0	Y3	1	0	0

Comparison of Frank-Wolfe algorithm with Bee-Algorithm are given in table7

Table 7 : The comparison of Frank-Wolfe algorithm with Bee-Algorithm

Maximum value of function	Frank-Wolfe Algorithm	Bee-Algorithm
F(X,Y)	**10.083**	**10.27327**
X	0.8333	0.9917915
Y	1.1666	1.412968

The Snapshot of Bee-Algorithm software in run mode for equation 2 are shown in figure 4

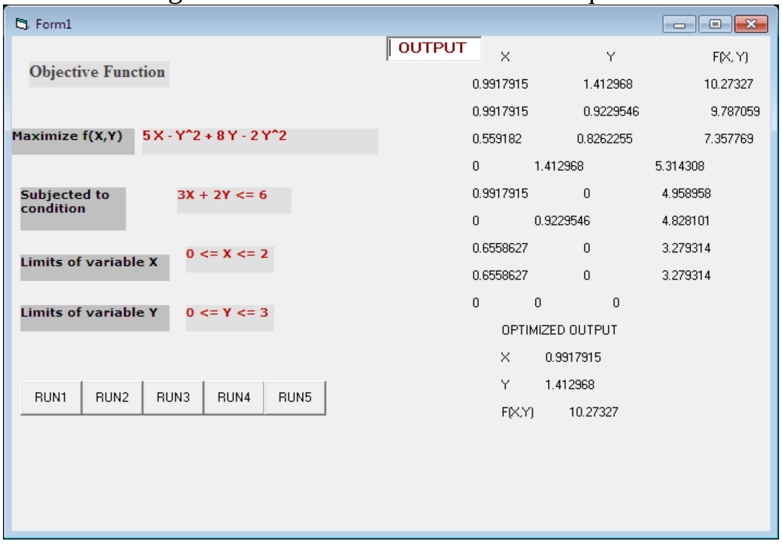

Figure4: Snapshot of Bee-Algorithm software in run mode for equation 2

Test problem 3

Objective Function

Maximize f(X,Y) = XY

Subject to $X^2 + Y \leq 3$

$0 \leq X \leq 1$

$0 \leq Y \leq 2$

Conventional technique

The objective function has been solved by Sequential Unconstrained Minimization Technique (SUMT). The details are reported in the literature[12].

The details of the comparison of the best values obtained in five consecutive runs are given in table 8 & the details of zone wise best values comparison for run 2 of eq.3 is given in table 9

Table 8: The details of the comparison of the best values obtained in five consecutive runs for eq.3

Sr.No.	Run No.	Max f(X,Y)	Best value of Max f(X,Y)
1	1	1.587956	**1.731563**
2	2	**1.731563**	
3	3	1.579024	
4	4	1.63411	
5	5	1.602357	

Table 9: The details of zone wise best values comparison for run 2 of eq.3

Details of 2nd run						
X zone	**X position**	**X value**	**Y zone**	**Y position**	**Y value**	**Function value**
X3	**5**	**0.9791054**	**Y3**	**5**	**1.768515**	**1.731563**
X2	2	0.6315268	Y3	2	1.647888	1.040685
X3	9	0.8626722	Y2	9	1.315982	1.135261

Details of 2^{nd} run						
X zone	X position	X value	Y zone	Y position	Y value	Function value
X2	2	0.6315268	Y2	2	1.219327	0.7700377
X3	8	0.8162779	Y1	8	0.6067889	0.4953083
X1	7	0.25912	Y3	7	1.855277	0.4807394
X2	8	0.4190114	Y1	8	0.6067889	0.2542515
X1	6	0.2988909	Y2	6	0.9701966	0.2899829
X1	9	0.208475	Y1	9	0.4142438	8.635947E-02

Comparison of optimum results obtained by using Sequential Unconstrained Minimization Technique and Bee-Algorithm are given in table 10

Table 10: The Comparison of optimum results obtained by using Sequential Unconstrained Minimization Technique and Bee-Algorithm

Maximum value of function	SUMT	Bee-Algorithm
F(X, Y)	**1.990**	**1.731563**
X	0.998	0.9791054
Y	1.994	1.768515

Figure 5 show the **S**napshot of Bee-Algorithm software in run mode for equation 3

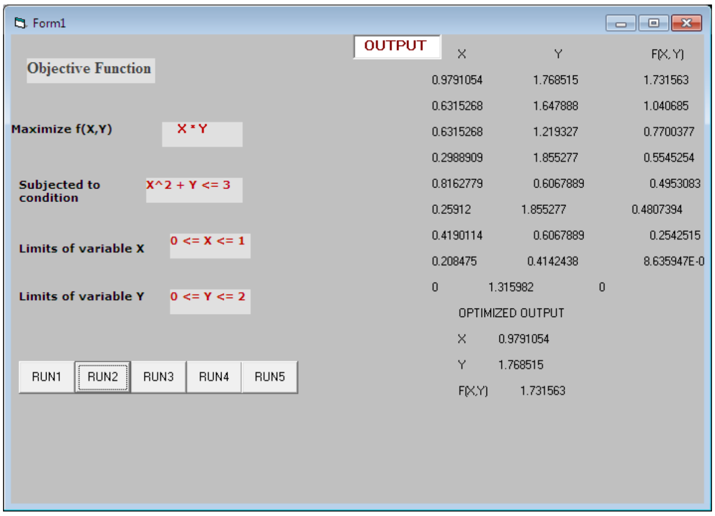

Figure 5: Snapshot of Bee-Algorithm software in run mode for equation 3

IV. RESULT & DISCUSSION

The present work is aimed at development of algorithm & source code for Bee-Algorithm & its validation using three test problem as explained in this section. The test problem selected are having two variables & function involved is coming in the category of non-linear constrained optimization . based on the output of the Bee-Algorithm for various runs & comparison of the best value obtained among these runs with best optimal value reported in the literature; the result & discussion are summarized as follow:

Test problem 1 involves the objective function & constraints as follows

Objective Function:

Maximize $f(X,Y) = 20 X + 16Y - 2X^2 - Y - (X+Y)^2$

Subject to $X + Y \leq 5$

$0 \leq X \leq 5$

$0 \leq Y \leq 5$

Table 11 show the optimum value obtained by conventional method, GA & Bee-Algorithm & their comparison is shown in the figure 6.

Table 11: the optimum value obtained by conventional method, GA & Bee-Algorithm

Methods	F(X, Y)
Penalty function	**46.333**
GA	**45.938**
Bee-Algorithm	**46.33154**

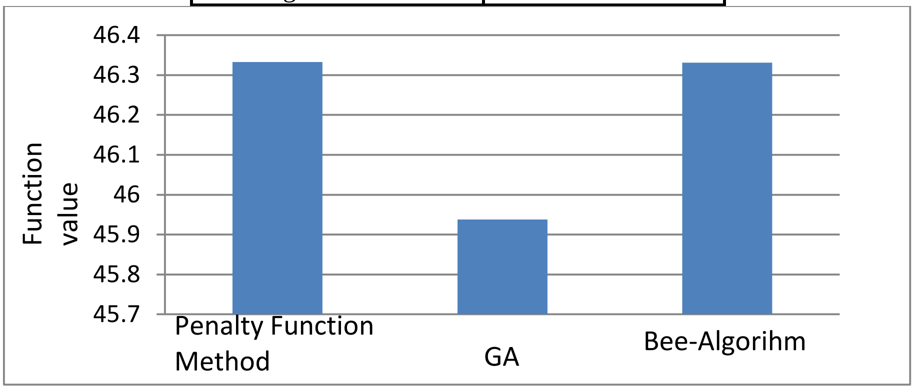

Fig.6: Comparison of the best values of optimal solution obtained from Penalty function method, GA & Bee-Algorithm

As can be seen from the graph of comparison the best optimal values obtained using Bee-Algorithm is coming fairly close to the values obtained using penalty function. The optimal solution obtaining using Bee-Algorithm is observed to be slightly superior to GA.

Test problem 2 involves the objective function & constraints as follows

Objective Function

Maximize $f(X,Y) = 5X - Y^2 + 8Y - 2Y^2$

Subject to $3X + 2Y \leq 6$

$0 \leq X \leq 2$

$0 \leq Y \leq 3$

Table 12 show the optimum value obtained by conventional method, GA & Bee-Algorithm & their comparison is shown in the figure 7.

Table 12: the optimum value obtained by conventional method, GA & Bee-Algorithm

Methods	F(X, Y)
Frank-Wolfe Algorithm	**10.083**
GA	**11.447**
Bee-Algorithm	**10.273**

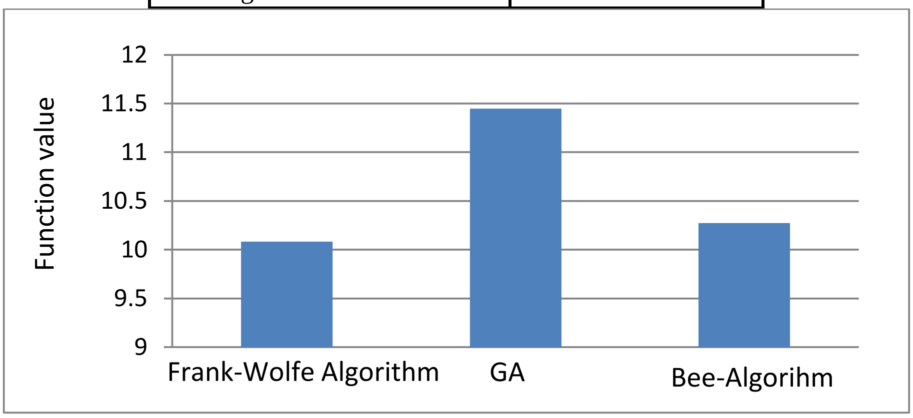

Fig. 7: Comparison of the best values of optimal solution obtained from Frank-Wolfe Algorithm, GA & Bee-Algorithm

As can be seen from the graph of comparison the best optimal values obtained using Bee-Algorithm is coming slightly superior to the values obtained using Frank-Wolfe Algorithm. The optimal solution obtaining using Bee-Algorithm is observed to be fairly close to GA.

Test problem 3 involves the objective function & constraints as follows

Objective Function

Maximize f(X,Y) = XY

Subject to $X^2 + Y \leq 3$

$0 \leq X \leq 1$

$0 \leq Y \leq 2$

Table 13 show the optimum value obtained by conventional method, GA & Bee-Algorithm & their comparison is shown in the figure 8.

Table 13: the optimum value obtained by conventional method, GA & Bee-Algorithm

Methods	**F(X, Y)**
SUMT	**1.990**
GA	**1.892**
Bee-Algorithm	**1.73125**

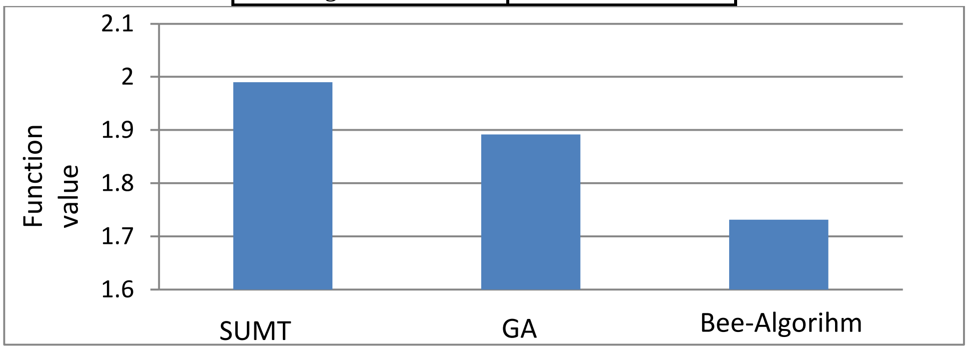

Fig.8: Comparison of the best values of optimal solution obtained from SUMT, GA & Bee-Algorithm

As can be seen from the graph of comparison the best optimal values obtained using Bee-Algorithm is coming fairly close to the values obtained using penalty function. The optimal solution obtaining using Bee-Algorithm is observed to be fairly close to GA.

V. CONCLUSION

In present work natural foraging behavior of honey bee is studied & it is converted logically & mathematically in algorithm. The developed bee-algorithm is then validated by using the three test problems taken from the literature & is compared with the conventional method. Based on result & discussion of comparison of optimal value obtained using Bee-Algorithm with conventional method & GA, it can be concluded that the present algorithm has been successful in addressing optimization of non-linear constrained function. The performance is close to the best optimal values of either conventional method or GA or even superior. It is observed the performance of Bee-Algorithm is fairly consistent & matching with the best conventional method inspite of variety in the optimization situation.

VI. FUTURE SCOPE

Given the variety of situation involving multivariable non-linear constrained functions for optimization solution there is need for further exploration in evaluating the performance of source code developed in present work to vary many different problems. Work is demonstrative however can be applied to innumerable optimization situation.

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