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# Optimizing of Robot Gripper Configurations Using Ant Colony Optimization

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## Abstract

*This Project is concerned with the determination of optimum forces extracted by robot grippers on the surface of a grasped rigid object – a matter which is crucial to guarantee the stability of the grip without causing defect or damage to the grasped object. A non-linear, complex, multi-constraint and multi-criteria optimization of robot gripper design problem is solved, involving two conflicting objectives and a number of constraints. The problem has five objective functions, nine constraints and seven variables. The objectives involve minimization of the difference between maximum and minimum gripping forces and simultaneous minimization of the transmission ratio between the applied gripper actuator force and the force experienced at the gripping ends. A robot gripper is designed by Ant colony Optimization and the obtained results are compared with a previous study.*

*Due to presence of geometric constraints, the resulting optimization problem is highly non-linear and multimodal. For both gripper configurations, the proposed methodology outperforms the results of the previous study. It is observed that one of the gripper configurations completely outperforms the other one from the point of view of both objectives, thereby establishing a complete bias towards the use of one of the configurations in practice.*



## 1. Introduction

Ant behaviour was the inspiration for the metaheuristic optimization technique the ant colony optimization algorithm (ACO), is a probabilistic technique for solving computational problems which can be reduced to finding good paths through graphs.

This algorithm is a member of ant colony algorithms family, in swarm intelligence methods, and it constitutes some metaheuristic optimizations. Initially proposed by Marco Dorigo in 1992 in his PhD thesis, the first algorithm was aiming to search for an optimal path in a graph; based on the behaviour of ants seeking a path between their colony and a source of food. The original idea has since diversified to solve a wider class of Numerical problems, and as a result, several problems have emerged, drawing on various aspects of the behaviour of ants.

The original idea comes from observing the exploitation of food resources among ants, in which ants' individually limited cognitive abilities have collectively been able to find the shortest path between a food source and the nest.

Deepak Tolani and Ambarish Goswami [1] developed a set of inverse kinematics algorithms suitable for an anthropomorphic arm or leg and used a combination of analytical and numerical methods to solve generalized inverse kinematics problems including position, orientation, and aiming constraints.

Andrzej Osyczka and Stanislaw Krenich [2] proposed 'Methods for multicriteria design optimization using evolutionary algorithms'. In this paper new multicriteria design optimization methods are discussed. These methods are evolutionary algorithm based methods, and their aim is to make the process of generating the Pareto front very effective. Firstly, the multistage evolutionary algorithm method is presented. In this method, in each stage only a bicriterion optimization problem is solved and then an objective function is transformed to the constrain function. The process is repeated till all the objective functions are considered. Secondly, the preference vector method is presented. In this method, an evolutionary algorithm finds the ideal vector. This vector provides the decision maker with the information about possible ranges of the objective functions.

M. H. Korayem, K. Khoshhal, and H. Aliakbarpour [3] a vision based system has been used for controlling an industrial 3P Cartesian robot. The vision system will recognize the target and control the robot by obtaining images from environment and processing them. At the first stage, images from environment are changed to a grayscale mode then it can diverse and identify objects and noises by using a threshold objects which are stored in different frames and then the main object will be recognized. This will control the robot to achieve the target.

Baki Koyuncu, and Mehmet Güzel [4] studied kinematics of manipulators is a central problem in the automatic control of robot manipulators. Theoretical background for the analysis of the 5 degree of freedom Lynx-6 educational Robot Arm kinematics is presented in this paper. The kinematics problem is defined as the transformation from the Cartesian space to the joint space and vice versa. The Denavit-Harbenterg (D-H) model of representation is used to model robot links and joints in this study.

T.C.Manjunath [5] designed an Artificial Intelligence based on Automatic Task Planner or a Robot System. This experiment deals with the design and the implementation of an automatic task planner for a robot, irrespective of whether it is a stationary robot or a mobile robot. The aim of the task planner nothing but, they are planning systems which are used to plan a particular task and do the robotic manipulation.

Chiara Lanni and Marco Ceccarelli [6] proposed 'An Optimization Problem Algorithm for Kinematic Design of Mechanisms for Two-Finger Grippers'. An analysis of mechanisms in two-finger grippers has been discussed to formulate an optimum design procedure.

## 2. Gripper Configuration Design

The motivation of the present work is to design the structure of a robot gripper optimally. The original problem was formulated elsewhere [7]. The goal of the optimization problem is to find the dimensions of elements of the grippers and optimize objective functions simultaneously by satisfying the geometric and force constraints. The two-dimensional structure of the gripping mechanism is shown in Figure 2. The vector of seven design variables are **x** = (*a, b, c, e, f, l, δ*)*T*, where *a, b, c, e, f, l* are dimensions (link lengths) of the gripper and *δ* is the angle between elements *b* and *c*. The structure of geometrical dependencies of the mechanism can be describing as follows (Figure 2):

$$g^2 = (l - z)^2 + e^2$$

$$\infty = \cos^{-1}\left(\frac{a^2+g^2-b^2}{2.a.g}\right) + \emptyset$$

$$b^2 = a^2 + g^2 - 2.a.g.\cos(\infty - \emptyset)$$

$$\emptyset = \tan^{-1}\left(\frac{e}{(l-z)}\right)$$

$$\beta = \cos^{-1}\left(\frac{b^2+g^2-a^2}{2.b.g}\right) - \emptyset$$

$$a^2 = b^2 + g^2 - 2.b.g.\cos(\beta + \emptyset)$$

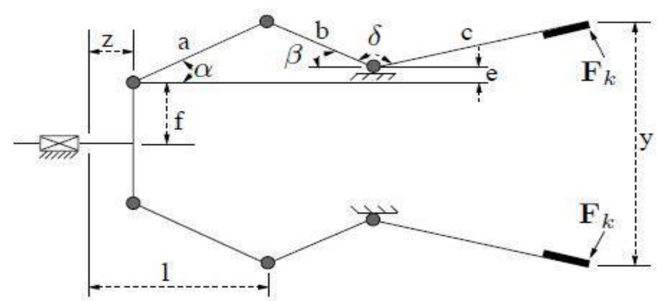


**Figure 1: A Sketch of Robot Gripper**

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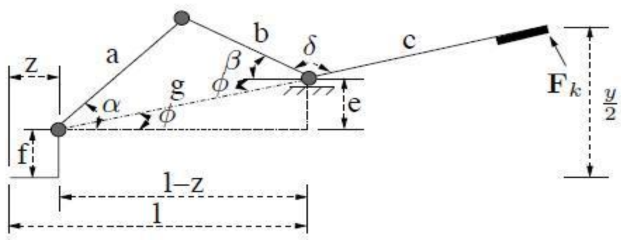


**Figure 2: Geometrical Dependencies of the Gripper Mechanism**

The free body diagram for the force distribution of is shown in Figure 3. From the figure, we can write the following:

$$R.\sin(\infty+\beta).\,b = F_k.\,c$$

$$R = \frac{P}{2.\cos\infty}$$

$$F_k = \frac{P.b.\sin(\infty+\beta)}{2.c.\cos\infty}$$

Where *R* is the reaction force on link *a* and *P* is the actuating force applied from the left side to operate the gripper

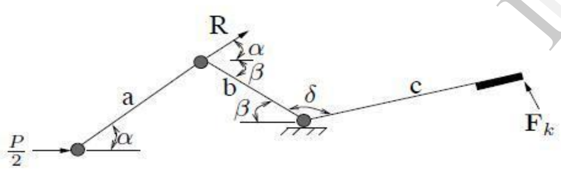


**Figure 3: Force distribution of mechanism of the gripper**

From the above correlations the objective functions can be formulated as follows:

1. $f_1(X)$: The function which describes the difference between maximum and minimum griping forces for the assumed range of the gripper ends displacements

$$f_1(X) = |\max z\, F_k(X,z) - \min z\, F_k(X,z)|$$

2. $f_2(X)$: The function which describes the force transmission ratio between the gripper actuator and the gripper ends

$$f_2(X) = \frac{P}{\min z\, F_k(X,z)}$$

3. $f_3(X)$: The function which describes the shift transmission ratio between the gripper actuator and the gripper ends.

$$f_3(X) = \left|\frac{y(X,z_{max}) - y(X,z_{min})}{z_{max}-z_{min}}\right|$$

4. $f_4(X)$ : The function which describes the lengths of all the elements of the gripper.

$$f_4(X) = a + b + c + e + l$$

5. $f_5(X)$ :The function which describes the efficiency of the gripper mechanism

$$f_5(X) = \left|\frac{2.\max z\, F_k(X,z)}{P}\right|$$



In the aforesaid multi-objective optimization problem, both objective functions depend on the vector of decision variables and on the displacement *z*. Thus for a given solution vector **x**, the values of the conflicting objective functions *f*1(**x**) and *f*2(**x**) requires that we find the maximum and minimum value of gripping force $F_k$(**x**, *z*) for different possible values of *z*. The parameter *z* is the displacement parameter which takes a value from zero to $Z_{max}$. Taking a small finite increment in *z*, recording the corresponding $F_k$ value for each *z*, and then locating the maximum and minimum values of $F_k$ is a computationally time-consuming proposition. Here, we employ the well-known golden section search algorithm for locating minimum and maximum $F_k$. It is important to note that these extreme values may take place at one of the two boundaries (either $z = 0$ or $z = Z_{max}$) and the golden section search is capable of locating them. The only drawback of the golden section search is that it can locate the minimum of a unimodal function accurately, but for multi-modal problems the algorithm is not guaranteed to find an optimum. Fortunately, for this problem, we have checked the nature of $F_k$ variation for a number of different solution vectors (**x**) and every time a unique maximum in the specified range of *z* is observed.

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## 3. Problem description

The problem contains five objective functions it is necessary to find the combined objective function, by introducing weight age factors it can be done in three cases

In the first case the combined objective function has the first two objective functions. In the second case the combined objective function has the last three objects functions. In the third case the combined objective function has all the five objective functions

**For the first case:**

$$F_1(X) = \left\{\left[\frac{w_1 f_1(X)}{f_1^*}\right] + \left[\frac{w_2 f_2(X)}{f_2^*}\right]\right\}$$

**For the second case:**

$$F_2(X) = \left\{\left[\frac{w_4 f_4(X)}{f_4^*}\right] - \left[\frac{w_3 f_3(X)}{f_3^*}\right] + \left[\frac{w_5 f_5(X)}{f_5^*}\right]\right\}$$

**For third case**

$$F_3(X) = \left\{\left[\frac{w_1 f_1(X)}{f_1^*}\right] + \left[\frac{w_2 f_2(X)}{f_2^*}\right] - \left[\frac{w_3 f_3(X)}{f_3^*}\right] + \left[\frac{w_4 f_4(X)}{f_4^*}\right] + \left[\frac{w_5 f_5(X)}{f_5^*}\right]\right\}$$

Where

The objective functions $f_1(X), f_2(X), f_4(X), f_5(X)$ are minimization functions while $f_3(X)$ is maximization function

The gripper problem also has a number of non-linear constraints:

1. The dimension between ends of gripper for maximum displacement of actuator should be less than minimal dimension of the gripping object:

$$g_1(\mathbf{x}) = Ym_{in} - y(\mathbf{x}, Z_{max}) \geq 0,$$

Where $y(\mathbf{x}, z) = 2.[e+f+c.\ \sin(\beta+\delta)]$ is the displacement of gripper ends and $Y_{min}$ is the minimal dimension of the griping object. The parameter $Z_{max}$ is the maximal displacement of the gripper actuator.

2. The distance between ends of gripper corresponding to Z max should be greater than zero:

$$g_2(\mathbf{x}) = y(\mathbf{x}, Z_{max}) \geq 0.$$

3. The distance between the gripping ends corresponding to no displacement of actuator (static condition) should be greater than the maximum dimension of gripping object:

$$g_3(\mathbf{x}) = y(\mathbf{x}, 0) - Y_{max} \geq 0,$$

Where $Y_{max}$ is the maximal dimension of the gripping object.

4. Maximal range of the gripper ends displacement should be greater than or equal to the distance between the gripping ends corresponding to no displacement of actuator (static condition):

$$g_4(\mathbf{x}) = Y_G - y(\mathbf{x}, 0) \geq 0,$$

Where $Y_G$ is the maximal range of the gripper ends displacement.

5. Geometrical properties are preserved by following two constraints:

$$g_5(x) = (a+b)^2 - l^2 - e^2 \geq 0.$$

$$g_6(x) = (l - Z_{max})^2 + (a-e)^2 - b^2 \geq 0.$$

The graphical illustration of constraint $g_5(x)$ and $g_6(x)$ is shown in Figure 4.

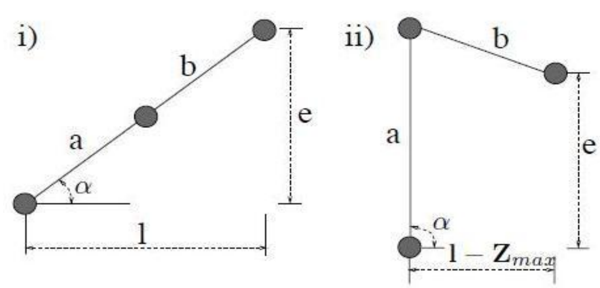


**Figure 4: Geometric illustrations of constraints i) g5 ii) g6 for Gripper**

6. From the geometry of the gripper the following constraint can be derived:

$$g_7(x) = l - Z_{max} \geq 0.$$

7. $g_8(x) = -1 \leq \frac{a^2+g^2-b^2}{2ag} \leq 1$

$g_9(x) = -1 \leq \frac{b^2+g^2-a^2}{2bg} \leq 1$

$g_8(x)$ and $g_9(x)$ are called trigonometric constrains.

## Ant colony search and results:

The problem has been solved in three cases by the Ant colony algorithm written in the C-language and these results are compared with the results of the pervious works using various other optimization methods

**Case-I:**

In the first case the combined objective function $F_1(X)$ has the first two objective functions, The ACO programme has been run for 150 iterations by changing different combinations of weightage factors, the results obtained from the different combinations are given in Table .1

| $w_1$ | $w_2$ | $F_1(X)$ |
|---|---|---|
| 1 | 0 | 5.001627 |
| 0 | 1 | 3.314930 |
| 0.9 | 0.1 | 4.997565 |
| 0.8 | 0.2 | 3.463474 |
| 0.7 | 0.3 | 3.486278 |
| 0.6 | 0.4 | 3.280734 |
| 0.5 | 0.5 | 3.369035 |
| 0.4 | 0.6 | 3.317617 |
| 0.3 | 0.7 | 3.275969 |
| 0.2 | 0.8 | 3.185431 |
| 0.1 | 0.9 | 3.148962 |

**Table 1: Results for the case-I by using ACO**

From the Table 8.1 it is found that the best results obtained at weightage factors 0.1 and 0.9 that indicates that 90 % priority must be given to the second objective function for the best results.

The results were compared with the existing work carried out by GA and DE were given in the Table 2 and it is noted that by comparison DE is dominating over other optimization Techniques.

| $w_1$ | $w_2$ | $F_1(X)$ | | |
|---|---|---|---|---|
| | | GA | DE | ACO |
| 1 | 0 | 5.001627 | 2.99215 | 5.001627 |
| 0 | 1 | 3.31493 | 3.065729 | 3.314930 |
| 0.9 | 0.1 | 4.997565 | 2.995663 | 4.997565 |
| 0.8 | 0.2 | 3.463474 | 2.892753 | 3.463474 |
| 0.7 | 0.3 | 3.486278 | 2.802054 | 3.486278 |
| 0.6 | 0.4 | 3.280734 | 2.711356 | 3.280734 |
| 0.5 | 0.5 | 3.369035 | 2.628743 | 3.369035 |
| 0.4 | 0.6 | 3.317617 | 2.534638 | 3.317617 |
| 0.3 | 0.7 | 3.275969 | 2.437639 | 3.275969 |
| 0.2 | 0.8 | 3.185431 | 2.221133 | 3.185431 |
| 0.1 | 0.9 | 3.148962 | 2.411829 | 3.148962 |

**Table 2: Comparison of minimal gripping force for case-I**

**Graphical results**

The history of the results obtained by the ACO programme for 150 Iterations has been plotted in the graph by considering number of iterations on X-axis and the Combined objective function value on Y-axis as shown in Fig. 5



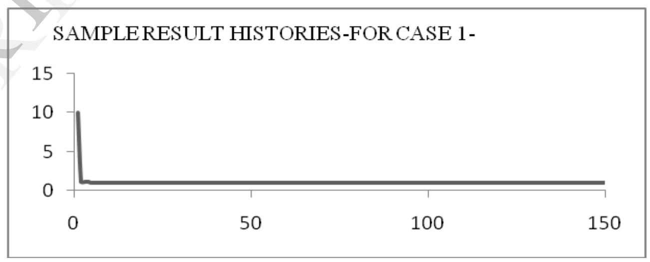


**Figure 5: sample result histories-case I using ACO**

It shows that there are some local minima for the starting iterations and from that onwards it was found that a constant value for the remaining iteration called as global minima, gives the esurience of working of the ACO programme

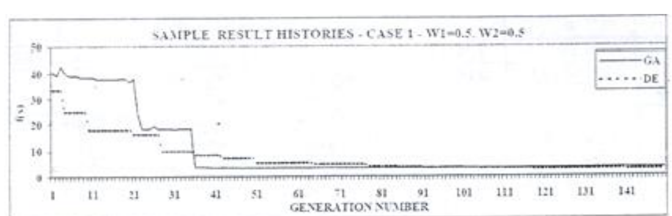


**Figure 6: Sample result histories-case 1 using GA and DE**

### Case-II:

In the Second case the combined objective function $F_2(X)$ has the last three objective functions, The ACO programme has been run for 150 iterations by changing different combinations of weightage factors, the results obtained from the different combinations are given in Table 3

| $w_1$ | $w_2$ | $w_3$ | $F_2(X)$ |
|---|---|---|---|
| 1 | 0 | 0 | 0 |
| 0 | 1 | 0 | 5.1765 |
| 0 | 0 | 1 | 1.8526 |
| 0.25 | 0.25 | 0.5 | 2.2242 |
| 0.5 | 0.25 | 0.25 | 1.7592 |
| 0.75 | 0.125 | 0.12 | 0.8796 |
| 0.25 | 0.5 | 0.25 | 3.0533 |
| 0.125 | 0.75 | 0.12 | 4.1149 |
| 0.125 | 0.125 | 0.75 | 2.0422 |

**Table 3: Results for the case-II by using ACO**

From the Table 3 it is found that the best results obtained at weightage factors 0.75, 0.125 and 0.125 that indicates that 75 % priority must be given to the third objective function for the best results.

The results were compared with the existing work carried out by GA and DE were given in the Table 8.4 and it is noted that by comparison ACO is dominating over other optimization Techniques.



| $w_1$ | $w_2$ | $w_3$ | $F_2(X)$ | | |
|---|---|---|---|---|---|
| | | | GA | DE | ACO |
| 1 | 0 | 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 5.752131 | 5.124947 | 5.1765 |
| 0 | 0 | 1 | 10.68117 | 4.580245 | 1.8526 |
| 0.25 | 0.25 | 0.5 | 6.36927 | 5.866 | 2.2242 |
| 0.5 | 0.25 | 0.25 | 5.225223 | 3.730513 | 1.7592 |
| 0.75 | 0.125 | 0.125 | 1.658227 | 1.492133 | 0.8796 |
| 0.25 | 0.5 | 0.25 | 4.960268 | 4.664124 | 3.0533 |
| 0.125 | 0.75 | 0.125 | 5.486759 | 5.414464 | 4.1149 |
| 0.125 | 0.125 | 0.75 | 5.978745 | 4.329177 | 2.0422 |

**Table 4 Compression of minimal gripping force for case-II**

### Graphical results

The history of the results obtained by the ACO programme for 150 Iterations has been plotted in the graph by considering number of iterations on X-axis and the combined objective function value on Y-axis as shown in Fig. 7

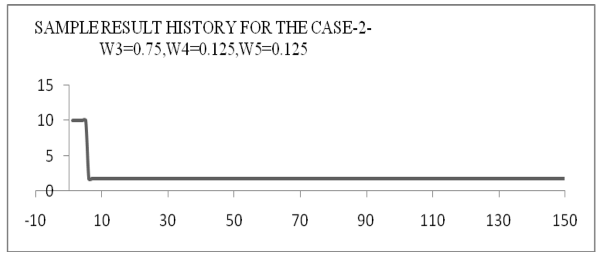


**Figure 7: Sample result histories-case 1 using ACO**

It shows that there are some local minima for the starting iterations and from that onwards it was found that a constant value for the remaining iteration called as global minima, gives the esurience of working of the ACO programme. This global minima was compared with the global minima of other techniques GA and DE shown in fig 8, it is found that the global minima of ACO is much earlier than the other techniques.

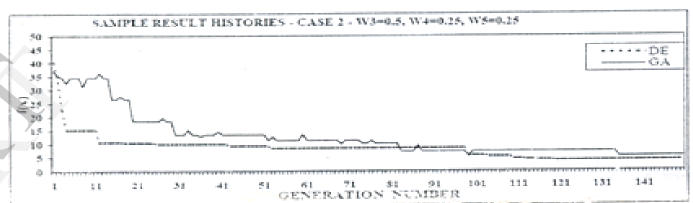


**Figure 8: sample result histories-case-2 using GA and DE**

### Case-III:

In the Second case the combined objective function $F_3(X)$ has the all five objective function, The ACO programme has been run for 150 iterations by changing different combinations of weightage factors, the results obtained from the different combinations are given in Table 5

| $w_1$ | $w_2$ | $w_3$ | $w_4$ | $w_5$ | $F_3(X)$ |
|---|---|---|---|---|---|
| 0.25 | 0.125 | 0.125 | 0.25 | 0.25 | 1.96 |
| 0.125 | 0.125 | 0.25 | 0.25 | 0.25 | 1.96 |
| 0.125 | 0.25 | 0.125 | 0.25 | 0.25 | 1.96 |
| 0.125 | 0.25 | 0.25 | 0.25 | 0.125 | 1.61 |
| 0.25 | 0.25 | 0.25 | 0.125 | 0.125 | 1.46 |

**Table 5: Results for the case-III by using ACO**

From the Table 5 it is found that the best results obtained at weightage factors 0.25, 0.25, 0.25, 0.125 and 0.125 that indicates that priority is distributed almost equally to all the objective functions.

The results were compared with the existing work carried out by GA and DE was given in the Table.6 and it is noted that by comparison ACO is dominating over other optimization Techniques.

| $w_1$ | $w_2$ | $w_3$ | $w_4$ | $w_5$ | $F_3(X)$ | | |
|---|---|---|---|---|---|---|---|
| | | | | | GA | DE | ACO |
| 0.25 | 0.125 | 0.125 | 0.25 | 0.25 | 2.35544 | 4.196048 | 1.96 |
| 0.125 | 0.125 | 0.25 | 0.25 | 0.25 | 2.996382 | 3.794172 | 1.96 |
| 0.125 | 0.25 | 0.125 | 0.25 | 0.25 | 2.402026 | 4.195571 | 1.96 |
| 0.125 | 0.25 | 0.25 | 0.25 | 0.125 | 4.94088 | 3.6485 | 1.61 |
| 0.25 | 0.25 | 0.25 | 0.125 | 0.125 | 2.323578 | 2.94608 | 1.46 |

**Table 6: Comparison of minimal gripping force for case-III**

**Graphical results**

The history of the results obtained by the ACO programme for 150 Iterations has been plotted in the graph by considering number of iterations on X-axis and the combined objective function value on Y-axis as shown in Fig. 9

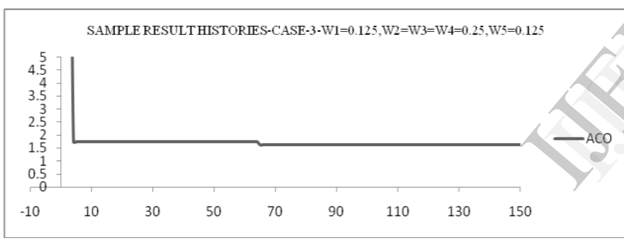


**Figure 9: sample result histories-case 1 using ACO**

It shows that there are some local minima for the starting iterations and from that onwards it was found that a constant value for the remaining iteration called as global minima, gives the esurience of working of the ACO programme. This global minima was compared with the global minima of other techniques GA and DE shown in Fig 10, it is found that the global minima of ACO is much earlier than the other techniques.

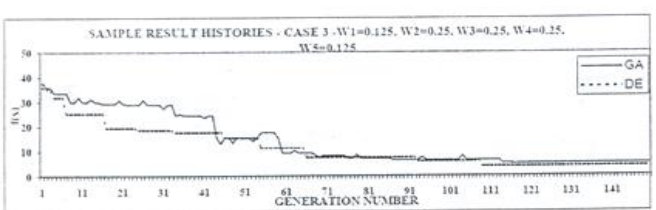


**Figure 10: Sample result histories-case-2 using GA and DE**



**Conclusions and future scope**

In this project new multicriterian design optimization. Methods based on swam intelligence algorithms are presented. The main aim of these methods are to reduce the computing time while running an evolutionary algorithm program and to facilitate the decision making process with multi objectives. This means that the methods make the process of seeking the preferred solution more effective considering both the computation time and the decision-making problem. Our study presents two novel and interesting methods for finding the optimum robot gripper configuration with multi objective functions.

The proposed algorithm (ACO) shows their superior nature while solving the problem. The proposed algorithms (ACO) are less time-consuming than GA & DE techniques.

From results and discussions, this project concludes that the proposed Ant Colony Optimization is superior in terms of accuracy and fastness than GA & DE. General-purpose software for the proposed ACO algorithm using C language is prepared and used, which can be used for any optimization problem.

Similar robot configurations will be optimized in future. This work opens the doors for further investigation on how nature based methods can be used to solve complex problems.

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