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Research Article

Dimensional Synthesis of Mechanism using Genetic Algorithm

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Abstract

Dimensional synthesis is systematic method for synthesis of mechanism. In this paper the GA is used for the dimensional synthesis to achieve a desired trajectory of coupler point. Genetic algorithm is optimization technique based on Natural Evolution Theory. It is based on the Darwin's principle survival of fittest in evolution. The GA employs three operators namely selection, crossover and mutation. The function used for optimization is Euclidean distance error function which describes the structural error between the desired trajectory and obtained trajectory. The analytical and graphical methods could not be used for this synthesis as the target points are more than five. Three problems are analyzed, first is to achieve a straight line of a coupler point without prescribed timing, second is to obtain an open curve having five desired points with prescribed timing and the third is to obtain a closed curve having eighteen desired points with prescribed timing. The program is authored in MATLAB®2010a. The error is seen to be in permissible prescribed limits.

Keywords: *Dimensional synthesis, genetic algorithm, path generation, precision points, six-bar mechanism, Stephenson-I.*

1. Introduction

The synthesis of mechanisms is usually employed to project or predict the functional dependence between geometry and the motions of various parts or links in mechanism under consideration. Conventionally the synthesis is classified into type synthesis, number synthesis and dimensional synthesis. The type synthesis refers to determining a type of mechanism when given upon input velocity, output velocity, prescribed path, etc. The number synthesis means determination of the number of links and the number of joints or pairs which are needed to achieve required mobility and path of output link. Finally the dimensional synthesis means determination of the dimensions of the individual links. The path generation i.e. straight line, circular, elliptical, is one of the assignments of dimensional synthesis. Further the path generation is acquired by either with prescribed timing while the angle of each prescribed point of coupler curve are required to be worked out or without prescribed timing while the angle of each prescribed point of coupler curve is given.

In the case of more than five points the Genetic Algorithm (GA) is implemented for dimensional synthesis. The GA is an optimization technique which is based on natural evolution theory and follows the Darwin's principle of survival of fittest. Professor John Holland investigated the concept of GA in mid-60 for explaining the adaptation process of natural system for creating artificial system that works similarly.

The classical graphical and analytical methods for the dimensional synthesis are discussed in Theory of Machines Mechanisms by Joseph Edward Shigley, which are restricted up to five precision points wherein the coupler curve is defined. (Cabrera *et, al*., 2002) formulated the GA and applied to optimize the Euclidean distance error function, which consists of two parts, namely Euclidean distance error function itself and the penalties if the applied constraints are not satisfied. This error function is the sum of squares of the difference between the desired path point and generated path point. The intension is to reduce the error between desired point and generated point after every iteration so that at the end of last iterations the error should be within prescribed limits. (Laribi *et. al.,* 2004) formulated the error function called as the orientation structural error of fixed link and employed the fuzzy logic controller to monitor the variations in the design variables during the first iteration of GA and then this fuzzy logic controller modifies initial bounding intervals or boundary values which will form the new boundary values for the second run of the GA.(Acharya *et. al.,* 2009) also implemented evolutionary algorithm for the synthesis of four bar mechanism. The different optimization techniques such as GA, differential evolution and particle swarm optimization are considered. Author analyses that, the

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performance of differential evolution is better than that of the other two optimization methods. (Cabrera *et. al.,* 2010) again implemented an algorithm which is the modification of previous algorithm and the name of this algorithm is Malaga University Mechanism Synthesis Algorithm (MUMSA). (Matekar *et. al.,* 2012) formulated new objective function and methodology for optimization. The modified distance error function is formulated based on longitudinal and transverse errors between prescribed path points and obtained path points. The limitation of using this objective function is that it cannot be used without prescribed timing. The crank angle for particular point must be known to solve the problem. (Han Jianyou *et. al.,* 2007) formed four bar linkages approximating a straight line. (Goldberg *et. al.,*) discussed different algorithms and their application with examples.

The knowledge of how to solve advanced dynamic concepts is vitally important in such areas as robotics, spacecraft, and multibody systems. Mechanisms and Robots Analysis with MATLAB® enables the reader to understand the mechanical behavior of complex engineering structures, mechanisms, and robots by discussing how to formulate the necessary mathematical equations and how to solve them using MATLAB®. Therefore, there is no extensive research work based on optimal syntheses of mechanisms with higher number of links. (Bulatovic *et. al., 2012*) have performed optimal synthesis of six-bar linkage for path generation using Differential Evolution technique.

Therefore, in present work, a six-bar Stephenson-I mechanism as well as four bar mechanism has been considered for optimal dimensional synthesis using genetic algorithm technique. Generally, in a mechanism, the coupler tracing point does not accurately follow the desired target points. In other words, the actual path followed by tracing point is slightly different from the desired path. Therefore, there exists an error between these two paths which is to be minimized.

2. Kinematic analysis of six-bar mechanism

Figure 1 represents a six-bar Stephenson-I mechanism, in which the link 1 is a binary link, fixed at points O and F. The link 2 is a ternary crank link which rotates about common point of link 1 and pivot O. The link 3 is a binary link whose one end is connected with link 2 at point B and other end is connected with a binary link 4 at point C. This point C is the tracing point. As link 2 rotates, the point C generates a trajectory for which the mechanism is to be dimensionally synthesized. The link 5 is a binary link whose one end is connected with link 2 at point A and other end is connected with a ternary link 6 at point E. The link 6 is a ternary rocker link which oscillates about common point of link 1 and pivot F. The coordinates of pivot point O are X1 and Y1 (Refer Fig. 2). Except pivot points O and F, the coordinates of all remaining points change as the mechanism generate path along the prescribed trajectory with the rotation of link 2.

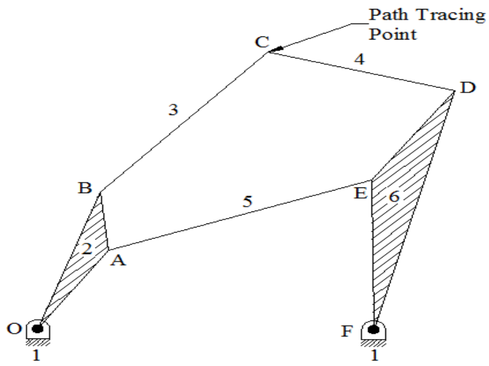


Fig.1 Configuration of six-bar mechanism

Link 2 is a ternary crank link which rotates about common point of link 1 and pivot O. The link 3 is a binary link whose one end is connected with link 2 at point B and other end is connected with a binary link 4 at point C. This point C is the tracing point. As link 2 rotates, the point C generates a trajectory for which the mechanism is to be dimensionally synthesized. The link 5 is a binary link whose one end is connected with link 2 at point A and other end is connected with a ternary link 6 at point E. The link 6 is a ternary rocker link which oscillates about common point of link 1 and pivot F. The coordinates of pivot point O are X_1 and Y_1 (Refer Fig. 2). Except pivot points O and F, the coordinates of all remaining points change as the mechanism generate path along the prescribed trajectory with the rotation of link 2.

Following parameters are used for the analysis of six-bar mechanism.

L_1 – Length of binary fixed link 1,
L_2, L_3, L_4 – Sides OB, OA and AB respectively of ternary crank link 2,
L_5 – Length of binary link 3,
L_6 – Length of binary link 4,
L_8 – Length of binary link 5
L_7, L_9, L_{10} – Sides DE, EF and DF respectively of ternary rocker link 6,

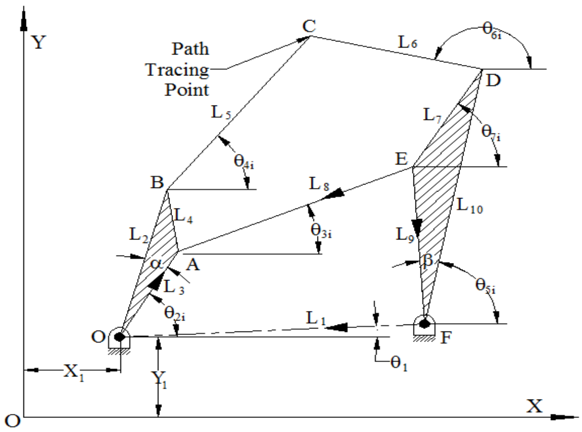


Fig.2 Parameters of six-bar mechanism

θ_1– Constant angle of binary fixed link 1 (L_1) with positive direction of OX-axis,

θ_{2i} – Variable angle of ternary crank link 1 with positive direction of OX-axis through which it rotates i.e. crank angle,
θ_{3i} – Variable angle of L_8 with positive direction of OX-axis,
θ_{4i} – Variable angle of L_5 with positive direction of OX-axis,
θ_{5i} – Variable angle of ternary rocker link 6 with positive direction of OX-axis through which it oscillates,
θ_{6i} – Variable angle of L_6 with positive direction of OX-axis,
θ_{7i} – Variable angle of L_7 with positive direction of OX-axis,
α – Included angle between L_2 and L_3.

$$\alpha = arccos\left|\frac{L_2^2+L_3^2-L_4^2}{2L_2L_3}\right| \qquad (1)$$

$$\beta = arccos\left|\frac{L_9^2+L_{10}^2-L_7^2}{2L_9L_{10}}\right| \qquad (2)$$

$$X_{Ai}=X_1 + L_3 \cos \theta_{1i} \qquad (3)$$

$$Y_{Ai}=Y_1 + L_3 \sin \theta_{1i} \qquad (4)$$

Now, the coordinates of the coupler point C whose path generating trajectory is desired are determined as follows.

Considering the dyad OBC and substituting the value of α from Eq. (1), the actual abscissa of the point 'C' is given by the expression

$$X_{Ci}^{a}=X_1 + L_2 \cos (\theta_{2i} + \alpha) + L_5 \cos \theta_{4i} \qquad (5)$$

Considering the quad OFEDC and substituting the value of β from Eq. (2), the actual ordinate of the point C is given by the expression

$$Y_{Ci}^{a}=Y_1 + L_1 \sin \theta_1 + L_9 \sin (\theta_{5i} + \beta) + L_7 \sin \theta_{7i} + L_6 \sin \theta_{6i} \qquad (6)$$

Independent vector loop OAEFO (Refer Fig. 2), the loop closure equation is given by the expression

$$\overrightarrow{L_8} = \overrightarrow{L_1} + \overrightarrow{L_3} + \overrightarrow{L_9} \qquad (7)$$

3. Optimal synthesis of six-bar mechanism

Figure 3 depicts the two paths followed by tracing point C of the given six-bar mechanism. The path represented by points $\{C_1^a, C_2^a, \ldots\ldots C_{12}^a,\}$ is the actual path and the path represented by points $\{C_1^d, C_2^d, \ldots\ldots C_{12}^d,\}$ is the desired path of tracing point C. Ideally these two paths should coincide with each other, but in actual practice, there is an error represented by hatch area as shown in Fig. 3. For the purpose that the actual path trajectory should exactly follow the desired path trajectory traced by the coupler point C, the optimal synthesis of six-bar mechanism involves determination of principal dimensions and orientation of each link so that the error between these two paths has minimum value. In any basic genetic algorithm, initially a random population of 2 times to 4 times of trial solutions is considered. E.g., if there is a two variable problem, then GA is started with 4 to 8 number of initial trial solutions expressed in decimal number.

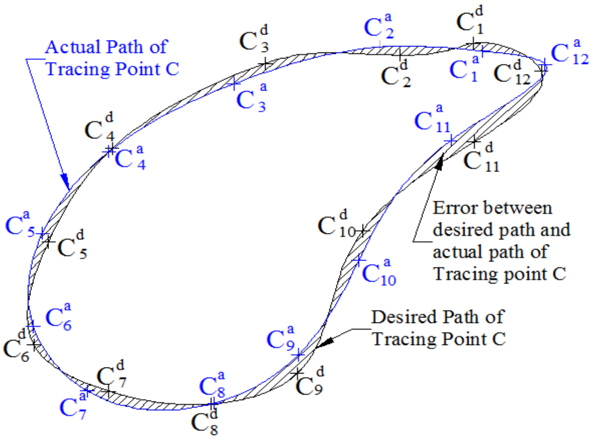


Fig. 3 Error between actual path and desired path of tracing point C

Each solution is first converted into a binary string of variables. The length of these binary string variables can be made large enough to achieve any desired fitness of even decimal values and thus any desired accuracy can be achieved. The numerical value of the objective function is calculated based on initial solution in decimal number. The objective function is arranged in ascending or descending order to find the best fittest solution. Corresponding to the fitness concept in genetics, those trial solutions are considered as fittest solution which optimize the objective function. Therefore, fittest member of species will survive and procreate. After trial solutions are selected, a new set of strings is produced by selecting the fittest parents to produce new children from among the trial solutions.

Crossover: In each child mixing and matching is performed from binary string bits of two parents to produce new children. These binary strings are converted back into decimal numbers to calculate new values of objective function again.

Mutation: While performing crossover, there are situations when the children are already having high fitness. In such conditions, the mating process of parents is continued by taking half chromosomes or string of fittest parent and remaining half from other parent to produce new children. It may happen that new child have efficiency poorer than its parent. To avoid this unwanted situation, mutation is performed. In mutation randomly bits are changed from 0 to 1 and vice versa. This is performed randomly and stochastically. Therefore undesirable effect of cross over is overcome.

Elitist Strategy: In Elitist strategy: out of total number of solutions, the best solution is not undergone in subsequent generation of GA operations. It goes to next generation automatically. The operations of binary conversion, crossover and mutation etc. are performed on all the solutions excluding the best solution. Therefore, the best solution is retained in next generation. But, it does not exist forever.

In next generation, the GA operations i.e. crossover and mutation are performed on all previous solutions excluding the best solution. If any new solution is found to be better than the previous best solution, then this new solution replaces the previous best solution. Therefore, best solution in a particular generation will not be subjected to GA operations. This strategy is called as Elitist Strategy.

4. Formulation of the Objective Function and the Constraint

For the purpose of reducing error between actual path followed and desired path of the coupler tracing point of mechanism, the objective function is minimized for the position error between actual points followed by coupler and desired points indicated by the designer. This position error is based on the square root of sum of square of Euclidean distances between each actual point P^a_{Ci} and corresponding desired Point P^d_{Ci}.

If { P^a_{Ci}}= $[X^a_{Ci}, Y^a_{Ci}]$ is a set of actual tracing points followed by coupler of mechanism corresponding to input angle{ θ_{1i} } and { P^d_{Ci}}= $[X^d_{Ci}, Y^d_{Ci}]$ is a set of desired points prescribed by the designer that should be followed by coupler of mechanism, then, for D precision points, the objective function can be expressed as,

$$f(X) = \sqrt{\sum_{i=1}^{D}[(X^a_{Ci} - X^d_{Ci})^2 + (Y^a_{Ci} - Y^d_{Ci})^2]} \qquad (8)$$

Substituting the values of X^a_{Ci} and Y^a_{Ci} in Eq. (8) from Eq. (5) and Eq. (6) respectively, we get

$$f(X) = \sqrt{\sum_{i=1}^{D} \begin{matrix}[(X_1 - L2\cos(\theta 2i + \alpha) + L5\cos\theta 4i - X^d_{Ci})^2 + \\ (Y_1 + L1\sin\theta 1 + L9\sin(\theta 5i + \beta) + L7\sin\theta 7i + L6\sin\theta 6i - Y^d_{Ci})^2]\end{matrix}} \qquad (9)$$

The various constraints are defined in the following way. Initial Limiting Values and Range of Design Variables. The initial values and range of design variables are defined by their upper and lower limits. The values of certain design variables must always be positive. These variables are length of fixed link (L_1), length of binary links (L_5, L_6 and L_8) and length of all sides of ternary crank and rocker link (i.e. L_2, L_3, L_4, L_7, L_9 and L_{10}). Therefore, the lower limit for each of these variables is set to greater than zero.

The initial value, range and incremental values for input angle i.e. crank angle (θ_{2i}) are prescribed by the designer. Therefore in Eq. (9) the crank angle (θ_{2i}) is substituted from lowest to highest values. The values for other link angles vary between positive to negative.

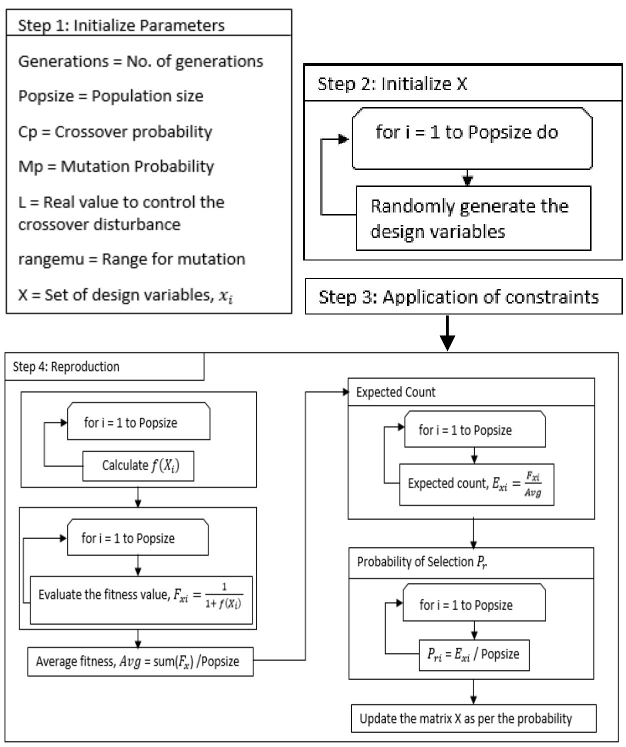
Ternary Link Check: As shown in Figure 2, there are two ternary links i.e. link 2 (OAB) and link 6 (DEF). Therefore, the optimal dimensions for each side of the two ternary links must have those values that constitute the sides of a triangle. For this purpose, a property of triangle formation is considered as a constraint. According to this property, a triangle is a valid triangle if and only if sum of its two sides is greater than the third side. Therefore, following constraint equations are considered while determining the optimized values of each ternary

$$L_2 + L_3 > L_4$$
$$L_3 + L_4 > L_2$$
$$L_4 + L_2 > L_3$$
$$L_7 + L_9 > L_{10}$$
$$L_9 + L_{10} > L_7$$
$$L_{10} + L_7 > L_9$$

The GA algorithm is written in such a way that it always selects initial population of variables that satisfies aforementioned constraints.

5. Optimization Algorithm

The optimization means evaluating best possible solution under given circumstances. The optimization is about obtaining value variables for minimum or maximum value of objective function. the GA is becoming an extremely popular in engineering design activities because of various computer programs and high computation speed. The flow chart of applied algorithm is given below.



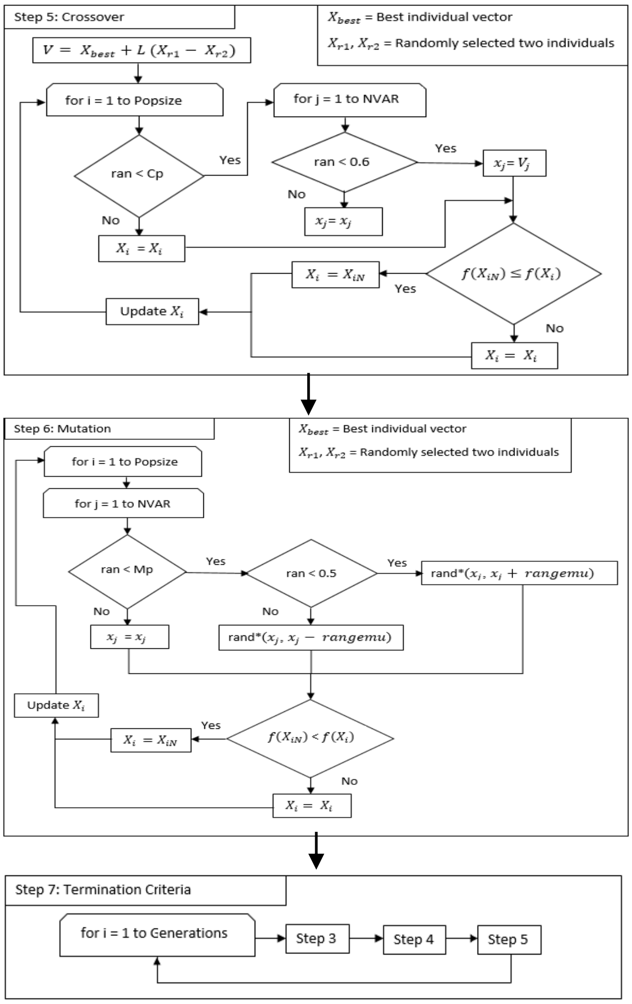


Fig. 4 Flow Chart of Genetic Algorithm

It is required to synthesize a six-bar mechanism which transmits motion along a path prescribed by number precision points.

6. Case Study

The first problem is path synthesis of a coupler point to generate straight line without prescribed timing for six bar mechanism.

6.1 Straight Line Generation Problem

To generate straight line having six anticipated points without prescribed timing.

Design variables are,

X = $[a, b, c, d, e, f, X_0, Y_0, \theta_1, \theta_2{}^1, \theta_2{}^2, \dots\dots.., \theta_2{}^6]$

Where, a, b, c, d, e, f = Links of the mechanism

Target points chosen:

$C_d{}^i$ = [(20,20),(20,25),(20,30),(20,35),(20,40),(20,45)]

Table 1 Synthesized Results for Straight Line Generation Problem

Design	Value	Design	Value
A	10.4657	$\theta_2{}^1$	5.33582
B	26.4562	$\theta_2{}^2$	5.52386
C	43.3573	$\theta_2{}^3$	5.69795
D	48.3378	$\theta_2{}^4$	5.86718
E	-9.9783	$\theta_2{}^5$	6.03998
F	-47.2007	$\theta_2{}^6$	6.22731
X_0	57.6963	θ_1	0.09769
Y_0	46.1450		

Limits of the variables:

$a, b, c, d\ \epsilon$[0,60]; $e, f, X_0, Y_0\ \epsilon$[-60,60] ;
$\theta_1, \theta_2{}^1, \theta_2{}^2, \theta_2{}^3, \theta_2{}^4, \theta_2{}^5, \theta_2{}^6 \epsilon$ [0, 2π].

Parameters considered are Generations=1000, Np=100, Cp = 0.9, Mp = 0.1, L = 0.6, range = 0.1. The total numbers of variables are 15 and target points are 6. The synthesized values of design variables are shown in Table 1. Second problem is of generating open curve for coupler with 5 prescribed points for six bar mechanism

6.1 Open curve Generation Problem

To generate open curve having five anticipated points with prescribed timing

Design variables are,
X = $[a, b, c, d, e, f]$

Target points chosen:

$C_d{}^i$ =[(3,3),(2.759,3.363),(2.372,3.663),(1.890,3.862),(1.355,3.943)] $\theta_2{}^i \epsilon$ [30 45 60 75 90]

Limits of the variables:

$a, b, c, d\ \epsilon$ [0, 5];$e, f \epsilon$ [-5,5];

Parameters considered are Generations = 200, Np=50, Cp = 0.9, Mp = 0.1, L = 0.6, Range = 0.1.

Table 2 Synthesized Results for Open Curve Generation Problem

Design Variable	Value
A	1.895902
B	3.80063
C	3.769618
D	2.378231
E	2.128029
F	1.238873

The total numbers of variables are 6 and target points are 5 with prescribed timing.

Third problem is of generating close curve for coupler with 18 prescribed points for six bar mechanism.

6.3 Closed Curve Generation Problem

To generate closed curve having 18 anticipated points with prescribed timing.

Design variables are

X = $[a, b, c, d, e, f, X_0, Y_0, \theta_1, {\theta_2}^1]$

Target points chosen: ${C_d}^i$ =[(0.5, 1.1),(0.4, 1.1), (0.3, 1.1), (0.2, 1.0), (0.1, 0.9),(0.005, 0.75),(0.02, 0.6),(0.0, 0.5),(0.0, 0.4),(0.03, 0.3),(0.1, 0.25),(0.15, 0.2),(0.2, 0.3),(0.3, 0.4),(0.4, 0.5),(0.5, 0.7),(0.6, 0.9),(0.6, 1.0)]

${\theta_2}^i \epsilon \left\{{\theta_2}^1, {\theta_2}^1 + 20 * i\right\}\ i : 1 \ldots \ldots 17$ Limits of the variables:$a, b, c, d\ \epsilon[0,5]$; $e, f, X_0, Y_0\ \epsilon$ [-5,5]; $\theta_1, {\theta_2}^1 \epsilon$ $[0,2\pi]$.Parameters considered are Generations = 100, Np=50, Cp = 0.85, Mp = 0.1, L = 0.5, range = 0.5.

Table 3 Synthesized Results for Closed Curve Generation Problem

Design Variable	Value
A	0.502813
B	4.376677
C	2.845285
D	4.594391
E	2.443179
F	0.812614
X_0	1.097455
Y_0	3.085219
${\theta_2}^1$	2.551369
θ_1	4.691002

The total numbers of variables are 10 and target points are 18 with prescribed timing.

7. Results and Discussion

The efficiency and accuracy of algorithm are verified for six bar mechanism by considering 3 problems. The first problem is path synthesis of a coupler point to generate straight line without prescribed timing and other two problems are considered with prescribed timing in which second problem is of generating open curve with 5 prescribed points while the third is of closed curve with 18 prescribed points.

7.1 Straight Line Generation Problem

In the first problem, the objective is to generate a straight line trajectory from a coupler point of the six bar mechanism. The actual points traced by coupler point for straight line generation and Euclidean distance function shown in Table 4.

The coupler point is the point on a triangular coupler link. The six bar mechanism contains six links namely input link, triangular coupler link, output link and fixed link as shown in Figure 1. The generated coupler curve is shown in Figure 5.1 and it is in elliptical shape but the right portion of generated elliptical curve is straight line and this straight line is passing through all desired points.
Initially the error is more than 6000 and it is reduced up to 1 after 100th generation. There are 1000 generations carried out and at the end of 1000th generation the error is 0.0088. It is seen from the graph that error is reduced rapidly from 6000 to 1 but after that more number of generations are required to minimize the error up to 0.0088. It is seen from the graph that error is reduced rapidly from 6000 to 1 but after that more number of generations are required to minimize the error up to 0.0088. The generated coupler curve passes through the desired points. Figure 5 shows coupler curve passing through the prescribed points. The GA program is written in MATLAB®2010a and graph of error verses generation number is plotted which is shown in Figure 6.

7.2 Open Curve Generation Problem

In this problem the objective is to form closed curve with prescribed timing from a coupler point of the six bar mechanism. There are 5 desired points through which the coupler point should pass. The corresponding values of desired points (P_{x_d}, P_{y_d}) and generated points by coupler point (P_x, P_y) and also error between them is shown in Table 5. The last column shows the error is very small and can be neglected. The minimum errors satisfy the objective function in the form of Euclidean distance function. The GA program is written in MATLAB®2010a.Figure 7 shows the coupler passes through 5 prescribed points and graph of error verses generation number is plotted which is shown in Figure 7. The error is reduced up to 1 after 10th generation. There are 200 generations carried out and at the end of 200th generation the error is 0.007. It is seen from the graph that error is reduced rapidly up to 1 but after that more number of generations are required to minimize the error up to 0.007.

7.3 Close Curve Generation Problem

In this problem the objective is to form closed curve with prescribed timing from a coupler point of the six bar mechanism. There are 18 desired points through which the coupler point should pass. The corresponding values of desired points (P_{x_d}, P_{y_d}) and generated points by coupler point (P_x, P_y) and also error between them is shown in Table 6. The last column shows the error is very small and can be neglected. The total error between desired and generated points is 0.06.

Table 4 Actual Points Traced by Coupler Point for Straight Line Generation Problem

Sr. No.	P_{x_d}	P_x	$(P_{x_d} - P_x)^2$	P_{y_d}	P_y	$(P_{y_d} - P_y)^2$	$(P_{x_d} - P_x)^2 + (P_{y_d} - P_y)^2$
1	20.0	19.96281	0.001383	20.0	19.99645	1.2602E-05	1.40E-03
2	20.0	20.00857	7.34E-05	25.0	25.00007	4.761E-09	7.34E-05
3	20.0	20.02686	0.000722	30.0	29.99997	8.41E-10	7.22E-04
4	20.0	20.0388	0.001505	35.0	34.99822	3.1541E-06	1.51E-03
5	20.0	20.02997	0.000898	40.0	39.99919	6.561E-07	8.99E-04
6	20.0	19.93483	0.004248	45.0	45.00122	1.4859E-06	4.25E-03

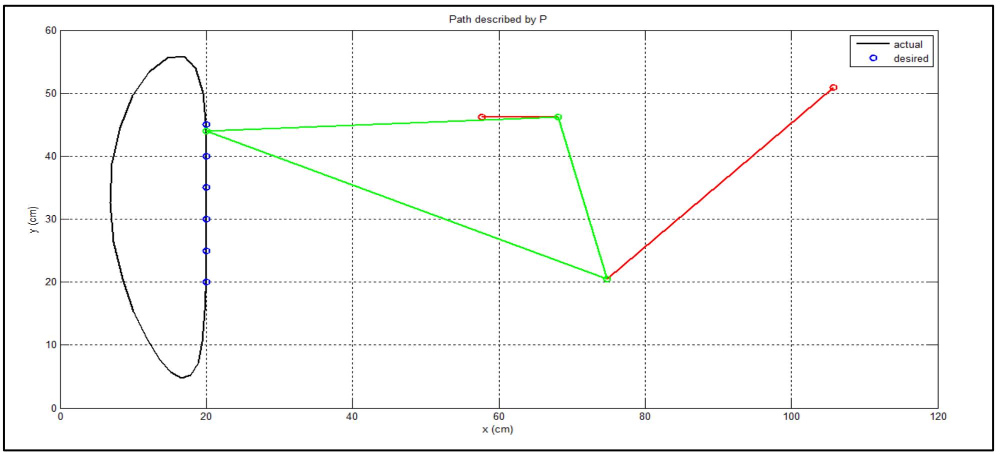


Fig. 5 Path Traced by Coupler Point for Straight Line Generation Problem

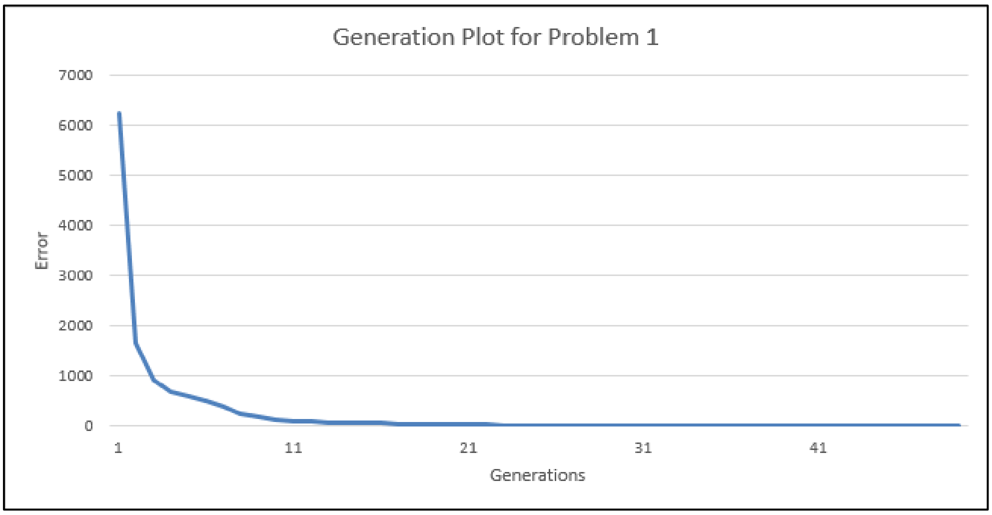


Fig. 6 Plot of Error Vs Generation Number for Straight Line Generation Problem

Table 5 Actual Points Traced by Coupler Point for Open Curve Generation Problem

Sr. No.	P_{x_d}	P_x	$(P_{x_d} - P_x)^2$	P_{y_d}	P_y	$(P_{y_d} - P_y)^2$	$(P_{x_d} - P_x)^2 + (P_{y_d} - P_y)^2$
1	3	2.964113	0.001288	3	3.028032	0.000786	0.002074
2	2.759	2.786526	0.000758	3.363	3.336676	0.000693	0.001451
3	2.372	2.401424	0.000866	3.663	3.632478	0.000932	0.001798
4	1.890	1.897124	5.08E-05	3.862	3.855392	4.37E-05	9.45E-05
5	1.355	1.323684	0.000981	3.943	3.975047	0.001027	0.002008

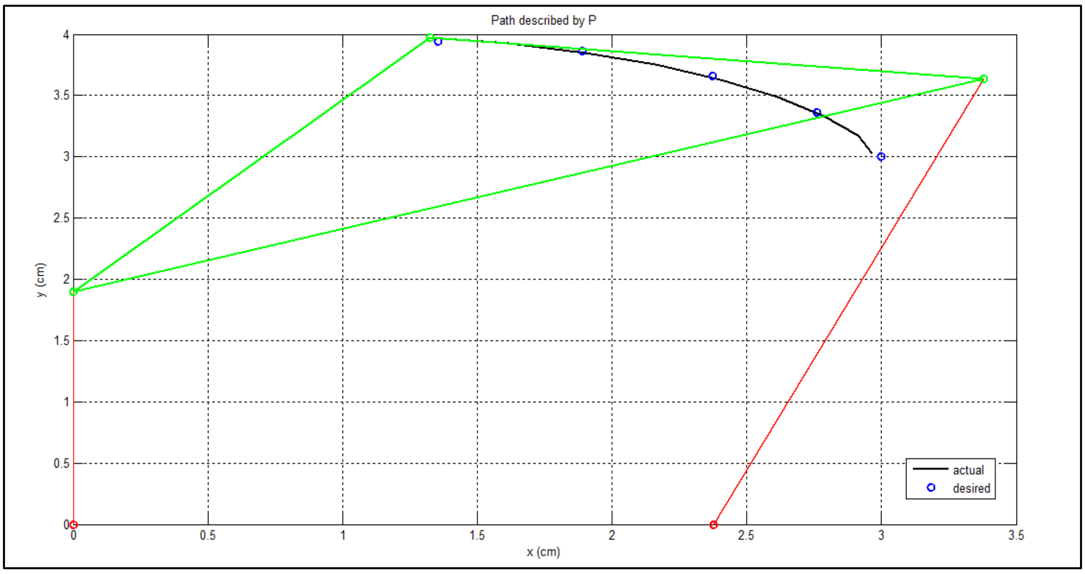


Fig. 7 Prescribed Points Traced by Coupler Point for Open Curve Generation Problem

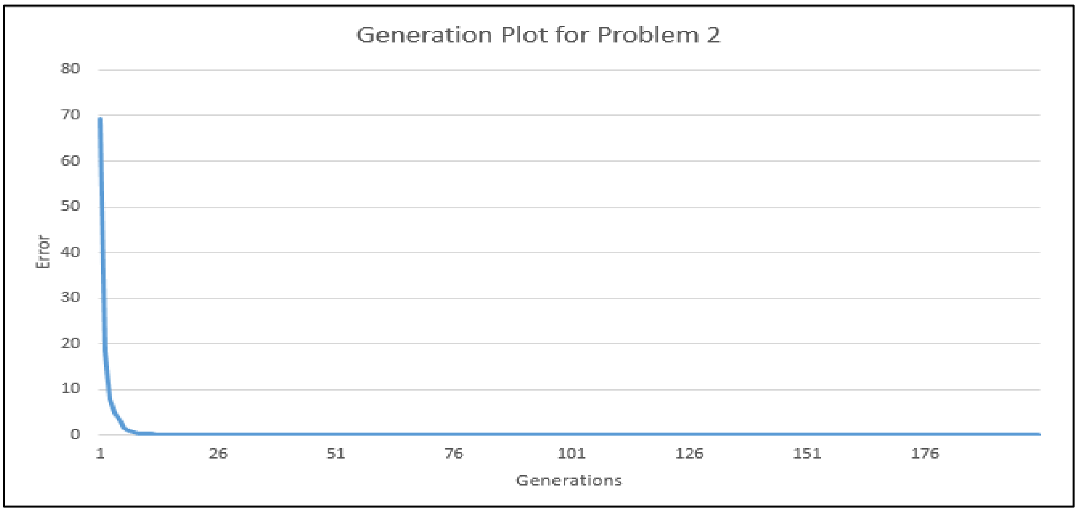


Fig. 8 Plot of Error Vs Generations Number for Open Curve Generation Problem

Table 6 Actual Points Traced by Coupler Point for Closed Curve Generation Problem

Sr. No.	P_{x_d}	P_x	$(P_{x_d}-P_x)^2$	P_{y_d}	P_y	$(P_{y_d}-P_y)^2$	$(P_{x_d}-P_x)^2+(P_{y_d}-P_y)^2$
1	0.5	0.487954	0.000145	1.1	1.083861	0.00026	0.000405
2	0.4	0.425838	0.000668	1.1	1.124157	0.000584	0.001252
3	0.3	0.339188	0.001536	1.1	1.112592	0.000159	0.001695
4	0.2	0.240469	0.001638	1	1.04836	0.002339	0.003977
5	0.1	0.144008	0.001937	0.9	0.936699	0.001347	0.003284
6	0.005	0.06332	0.003401	0.75	0.789134	0.001531	0.004932
7	0.02	0.008536	0.000131	0.6	0.622694	0.000515	0.000646
8	0	-0.01532	0.000235	0.5	0.458178	0.001749	0.001984
9	0	-0.00855	7.31E-05	0.4	0.317618	0.006787	0.0068601
10	0.03	0.024661	2.85E-05	0.3	0.221071	0.00623	0.0062585
11	0.1	0.078804	0.000449	0.25	0.182893	0.004503	0.004952
12	0.15	0.149043	9.16E-07	0.2	0.208225	6.77E-05	6.8616E-05
13	0.2	0.230927	0.000956	0.3	0.291432	7.34E-05	0.0010294
14	0.3	0.318202	0.000331	0.4	0.41807	0.000327	0.000658
15	0.4	0.401379	1.9E-06	0.5	0.569507	0.004831	0.0048329
16	0.5	0.468892	0.000968	0.7	0.727184	0.000739	0.001707
17	0.6	0.509919	0.008115	0.9	0.874597	0.000645	0.00876
18	0.6	0.51706	0.006879	1	0.997514	6.18E-06	0.00688518

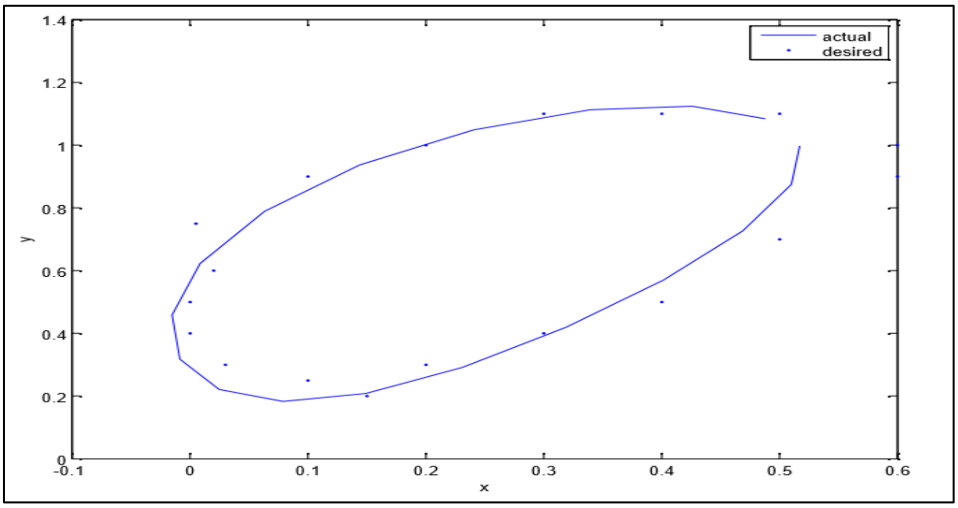


Fig. 9 Prescribed Points Traced by Coupler Point for Closed Curve Generation Problem

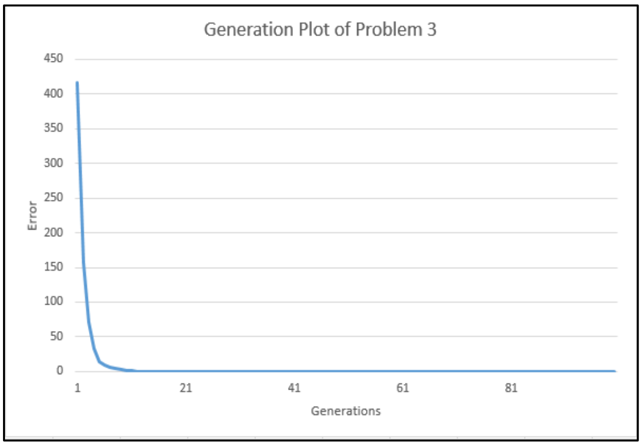


Fig 10 Plot of Error Vs Iteration Number for Closed Curve Generation Problem

Conclusion

Dimensional synthesis using genetic algorithm is successfully implemented to six bar mechanism. Following are the conclusions derived from results.
In the present dissertation work, the six bar mechanism is considered and three different problems from the literature are analyzed. The first is the straight line generation without prescribed timing, second is open curve with prescribed timing and third is closed curve with prescribed timing.

1) The Euclidean distance error function is formulated as objective function and constraints are applied successfully.
2) For six bar mechanism the straight line generation problem the error is reduced up to 0.008 and also in open and closed curve generation problem, the error is reduced up to 0.007 and 0.06 respectively and obtained coupler curves are analogues with the desired curves.
3) The optimal dimensions of each link and it's orientations for six bar mechanism are calculated so that generated coupler curve follows straight line, open curve and close curve using Genetic Algorithm
4) The genetic algorithm allows number of design variables and there is no restriction on target points as compared with conventional analytical and graphical methods. Therefore GA gives better results than the analytical and graphical results.

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