Simulation of Robotic Arm using Genetic Algorithm & AHP

V. K. Banga, Y. Singh, and R. Kumar

Abstract—In this paper, we have proposed a low cost optimized solution for the movement of a three-arm manipulator using Genetic Algorithm (GA) and Analytical Hierarchy Process (AHP). A scheme is given for optimizing the movement of robotic arm with the help of Genetic Algorithm so that the minimum energy consumption criteria can be achieved. As compared to Direct Kinematics, Inverse Kinematics evolved two solutions out of which the best-fit solution is selected with the help of Genetic Algorithm and is kept in search space for future use. The Inverse Kinematics, Fitness Value evaluation and Binary Encoding like tasks are simulated and tested. Although, three factors viz. Movement, Friction and Least Settling Time (or Min. Vibration) are used for finding the Fitness Function / Fitness Values, however some more factors can also be considered.

Keywords—Inverse Kinematics, Genetic Algorithm (GA), Analytical Hierarchy Process (AHP), Fitness Value, Fitness Function.

I. INTRODUCTION

ROBOTIC arm are commonly used in industries. In many field applications where technical support is required, man-handling is either dangerous or is not possible. In such situations three or more arm manipulators are commonly used. They are on great demand to speed up the automation process [1, 4, 6].

Three link manipulators are the fundamental robotic arms, which are still used in micro to macro scale applications viz. chip fabrications to huge mechanical actuators used in chemical processes [5, 8]. The literature survey reveals that there is need to optimize the movement for energy consumption and various mechanical and control related attributes like friction, settling time etc., which will improve the performance [2, 3].

Genetic algorithms are often viewed as function optimizers, although the range of problems to which genetic algorithms have been applied is quite broad. An implementation of a genetic algorithm begins with a population of (typically random) chromosomes. These structures evaluate and allocate reproductive opportunities in such a way that those chromosomes, which represent a better solution to the target problem are given more chances to reproduce than those chromosomes which are poorer solutions [7].

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Analytical Hierarchy Process is a pragmatic way of reaching a best solution from a given search space without modifying the solution. This method is intensively used for solving the corporate problems related to finance, marketing etc.. AHP has proved itself to be one of the best available methods to find the ranks or fitness values based on the application objectives.

II. OVERVIEW

In this paper, a 3-link manipulator is considered on which inverse kinematics is applied. For each link's angle, we have obtained two solutions. These six angles form 8-chromosomes population. AHP is applied for obtaining fitness function. Initially, for the first two runs, the magnitudes of the angles are large. After second run, the magnitudes of the angles decrease to a great extent and then binary encoding and mutation operations are performed.

In this work, GA searches most optimal solution for three constraints viz. Movement, Friction and Least Settling Time (or Min. Vibration), taken into account. Software code has been evolved, which does off-line testing and simulation, for various cases.

For this purpose, the inverse kinematics solutions are considered, which provide two solutions for each link's angle. These are further used to generate the eight chromosomes population to be fed into the GA. AHP finds the fitness functions. After third run of GA, we found that the population of the chromosomes obtained after the first run is the most optimized solution in the case of three-link manipulator movement.

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III. Proposed Optimization Scheme

The robotic arm specifications [9, 10] (described in the next section) are the inputs for optimization scheme (Fig. 1). Inverse Kinematics is applied on these specifications and two solutions are obtained for each link angle. Three links each having two solutions in total gives six angles. These six angles are arranged in a way that eight combinations are obtained. These eight combinations / solutions are fed to Genetic Algorithm which generates the new population with the help of AHP.
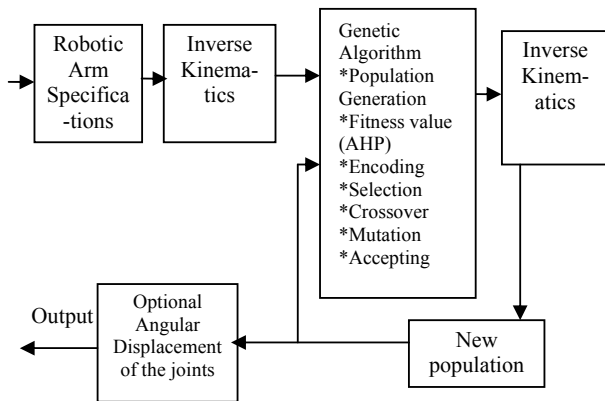

Fig. 1 Block diagram of the System

If the new population is matched with the desired results, the population is stored in the search space, otherwise the inverse kinematics is again applied to the newly obtained population and the whole procedure is repeated till the required or desired results are obtained.

IV. Hardware

A vertical Articulated Robotic Arm with 3 links (Fig. 2) having length 330 mm, 320 mm and 265 mm respectively, is considered which has a 5^0 of freedom and has a weight carrying capacity of 1.4 kg.
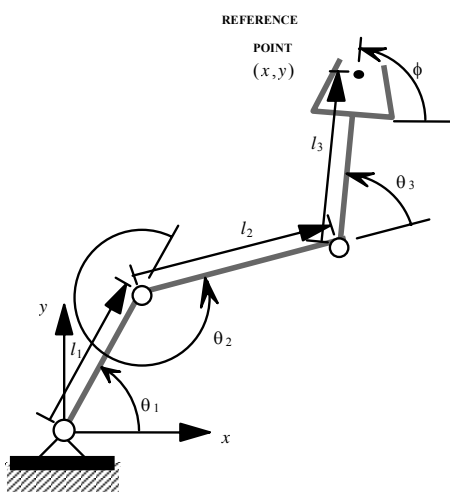

Fig. 2 Three link manipulator

Having a weight of 25 kg, power specification of 200-240 V AC ±10%, 50/60 Hz, 0.5 kVA; it can give accurate results with in the range of 5-40 ^{0}C ambient temperature and 45-85 % (non-condensing) humidity.

It has a capability of withstanding vibrations of 3.5 G or less during transportation and 0.5 G or less during operation.

V. System Model Development

A. Robotics and Inverse Kinematics

Having the lengths of the three links as 330 mm (l_1), 320 mm (l_2) and 265 mm (l_3) respectively, we choose to move the end effector form reference point $(0,0,0)$ to the destination point i.e. $(50, 25, 26.565^0)$. These specifications are fed to the three inverse kinematics fundamental equations:

$$x = l_1 \cos \theta_1 + l_2 \cos (\theta_1 + \theta_2) + l_3 \cos (\theta_1 + \theta_2 + \theta_3) \qquad -(1)$$
$$y = l_1 \sin \theta_1 + l_2 \sin (\theta_1 + \theta_2) + l_3 \sin (\theta_1 + \theta_2 + \theta_3) \qquad -(2)$$
$$\varnothing = \theta_1 + \theta_2 + \theta_3 \qquad -(3)$$

Solving these equations we get the following values for the angles of the links:

$$\theta_1 = 137.911^0, \quad -84.781^0$$
$$\theta_2 = -217.49^0, \quad 37.491^0$$
$$\theta_3 = 106.144^0, \quad 73.855^0$$

B. Genetic Algorithm

Now these results are fed to the Genetic Algorithm for generating the population of chromosomes having optimized values.

[start] Generate random population of *n* chromosomes (suitable solutions for the problem).

[fitness] Evaluate the fitness *f(x)* of each chromosome *x* in the population.

[new population] Create a new population by repeating following steps until the new population is complete.

> **a. selection.** Select two parent hromosomes from a population according to their fitness (the better fitness, the bigger chance to be selected).
>
> **b. crossover.** With a crossover probability, cross over the parents to form new offspring (children). If no crossover was performed, offspring is the exact copy of parents.
>
> **c. mutation.** With a mutation probability, mutate new offspring at each locus (position in chromosome).
>
> **d. Accepting.** Place new offspring in the new population.

[replace] Use new generated population for a further run of the algorithm.

[test] If the end condition is satisfied, **stop**, and return the best solution in current population.

[loop] Go to step 2.

C. Analytical Hierarchy Process (AHP)

The analytic hierarchy process is a process which Structure a problem as a hierarchy or as a system, elicit judgments that reflect ideas, feelings and emotions, represent those judgments with meaningful numbers, synthesize results and analyze sensitivity to changes in judgment.

The purpose of AHP is to structure complexity in gradual steps from the large to the small, or the general to the particular, so that we can relate them with greater accuracy according to our understanding. Because experience is too vast to lay it out in a single network structure, we are satisfied with piecemeal decompositions and with occasional linkages of them. The purpose is to improve our awareness by richer synthesis of our knowledge and intuition. The AHP is a learning tool. It is not a means to discover the TRUTH because truth is relative and changing. In the AHP, next to setting up a STRUCTURE to represent a problem, the reciprocal property is the most fundamental aspect for creating a SCALE.

A hierarchy is an efficient way to organize complex system, and functionally, for controlling and passing information down the system. Unstructured problems are best grappled with in the systematic framework of the hierarchy or a feedback network. In our case Fitness of each chromosome depends upon many factors. We will consider three mains factors on which the fitness function will be calculated by applying Analytical Hierarchical Process. These three main factors are: Movement (A1), Friction (A2),

Least Settling Time (Min. Vibration) (A3).

First we will decide the importance and value of these three attributes for the each angle separately.

Table I for angle θ1 which is the angle moved by link-1.

TABLE I
IMPORTANCE AND VALUE OF THE THREE ATTRIBUTE FOR Θ_1

Attribute	Importance	Value (total 1)
A_1	High	0.5
A_2	Low	0.2
A_3	Medium	0.3

TABLE II
IMPORTANCE AND VALUE OF THE THREE ATTRIBUTE FOR Θ_2

Attribute	Importance	Value (total 1)
A_1	Medium	0.3
A_2	High	0.5
A_3	Low	0.2

TABLE III
IMPORTANCE AND VALUE OF THE THREE ATTRIBUTE FOR Θ_3

Attribute	Importance	Value (total 1)
A_1	Medium	0.3
A_2	Medium	0.3
A_3	High	0.4

Finding the Eigen values of these comparison matrices and then taking the maximum values of the Eigen values we have *$\lambda_1 (\theta_1)$ is 2.99, $\lambda_2 (\theta_2)$ is 2.98 and $\lambda_3(\theta_3)$ is 2.99* and the corresponding Fitness Function is given below by equation (4):

$$f(x) = \theta_1 \times \lambda + \theta_2 \times \lambda + \theta_3 \times \lambda \qquad (4)$$

VI. SIMULATION AND TESTING

Maximum reach of the robot arm: 915 mm
Length of first link (l1):   330 mm
Length of second link (l2): 320 mm
Length of third link (l3):   265 mm
Origin or reference
 point (O) coordinates: (0, 0, 0)
Destination point (P) coordinates: (x, y, ø)
        x: 50 mm
        y: 25 mm

The system flow chart (Fig. 3) has been considered for developing the software code using GA (whose flowchart is shown in Fig. 4), AHP (whose flowchart is shown in Fig. 5) and 3-link Robotic Model.
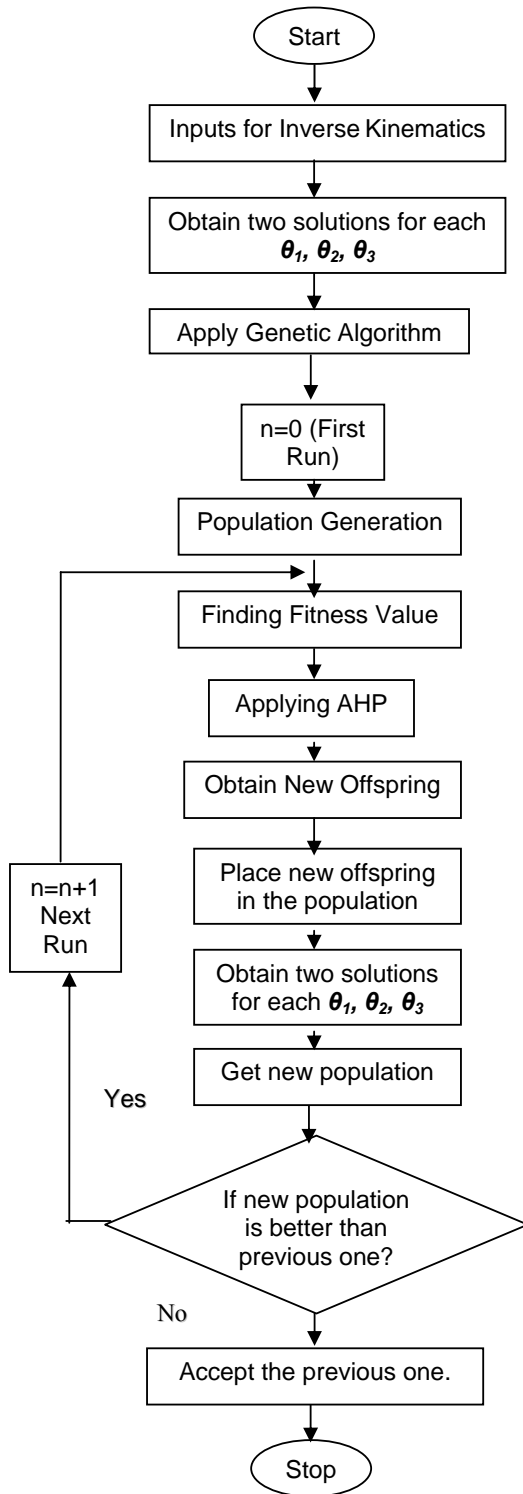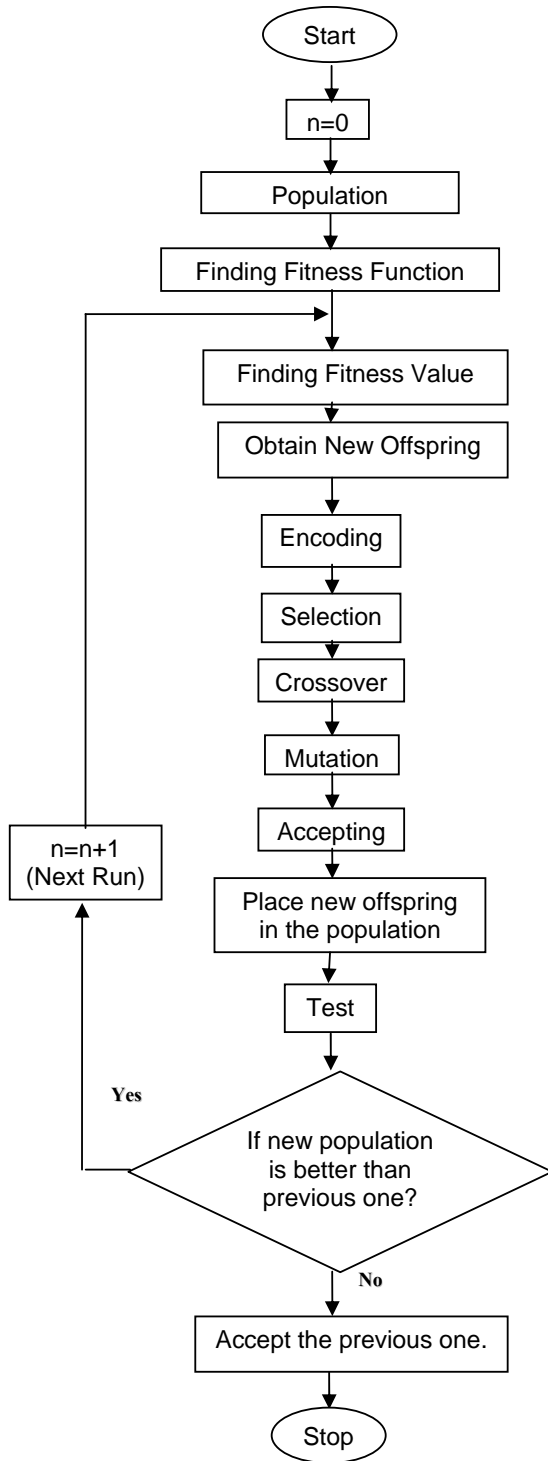
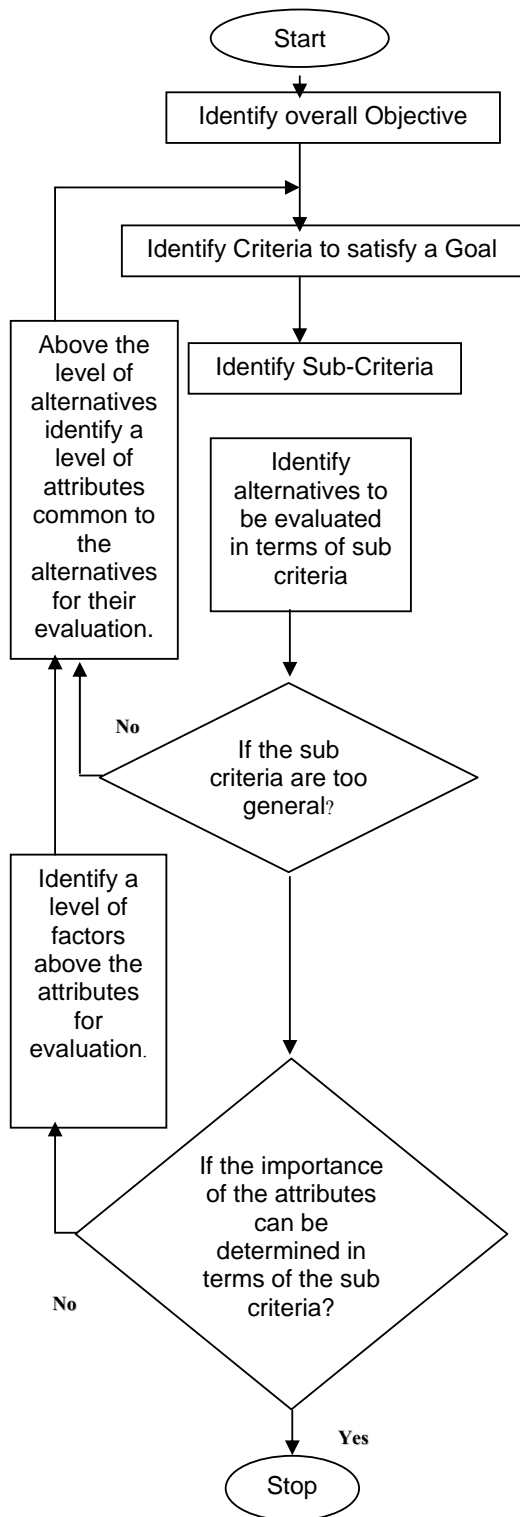Fig. 3 System Flow Chart

Fig. 4 Genetic Algorithm Flow chart

Fig. 5 Analytical Hierarchy Process Flow Chart

By applying the inverse kinematics initially and then from the three runs performed during the design and development for the optimization process, we obtain the following population as illustrated in Tables IV, V, VI and VII.

1) From inverse kinematics

TABLE IV
POPULATION FROM INVERSE KINEMATICS

Cr. No.	Chromosome	Fitness value
1.	$\{137.91^0, 217.49^0, 106.14^0\}$	1377.84
2.	$\{137.91^0, 217.49^0, 73.85^0\}$	1281.28
3.	$\{137.91^0, 37.49^0, 106.14^0\}$	841.44
4.	$\{137.91^0, 37.49^0, 73.85^0\}$	744.88
5.	$\{84.78^0, 37.49^0, 106.14^0\}$	682.59
6.	$\{84.78^0, 37.49^0, 73.85^0\}$	586.03
7.	$\{84.78^0, 217.49^0, 106.14^0\}$	1218.99
8.	$\{84.78^0, 217.49^0, 73.85^0\}$	1122.43

2) From First Run

TABLE V
POPULATION FROM FIRST RUN

Cr. No.	Chromosome	Fitness value
9.	$\{20.84^0, 36.95^0, 103.84^0\}$	482.90
10.	$\{20.84^0, 36.95^0, 76.15^0\}$	400.11
11.	$\{20.84^0, 28.75^0, 103.84^0\}$	458.47
12.	$\{20.84^0, 28.75^0, 76.15^0\}$	375.68
13.	$\{40.33^0, 36.95^0, 103.84^0\}$	541.18
14.	$\{40.33^0, 36.95^0, 76.15^0\}$	458.39
15.	$\{40.33^0, 28.75^0, 103.84^0\}$	516.75
16.	$\{40.33^0, 28.75^0, 76.15^0\}$	433.96

2) From Second Run

TABLE VI
POPULATION FROM SECOND RUN

Cr. No.	Chromosome	Fitness value
17.	$\{137.91^0, 26.95^0, 84.40^0\}$	742.30
18.	$\{137.91^0, 26.95^0, 150.10^0\}$	938.74
19.	$\{137.91^0, 38.75^0, 84.40^0\}$	777.47
20.	$\{137.91^0, 38.75^0, 150.10^0\}$	973.91
21.	$\{84.78^0, 26.95^0, 84.40^0\}$	586.16
22.	$\{84.78^0, 26.95^0, 150.10^0\}$	782.60
23.	$\{84.78^0, 38.75^0, 84.40^0\}$	621.31
24.	$\{84.78^0, 38.75^0, 150.10^0\}$	817.77

3) From Third Run

TABLE VII
POPULATION FROM THIRD RUN

Cr. No.	Chromosome	Fitness value
25.	$\{137.91^0, 16.75^0, 84.40^0\}$	713.43
26.	$\{137.91^0, 16.75^0, 172.30$	977.44
27.	$\{137.91^0, 60.95^0, 84.40^0\}$	845.14
28.	$\{137.91^0, 60.95^0, 172.30^0\}$	1109.16
29.	$\{84.78^0, 16.75^0, 84.40^0\}$	555.57
30.	$\{84.78^0, 16.75^0, 172.30^0\}$	818.58
31.	$\{84.78^0, 60.95^0, 84.40^0\}$	686.28
32.	$\{84.78^0, 60.95^0, 172.30^0\}$	950.30

VII. RESULTS AND DISCUSSIONS

In the first run, we are unable to perform the cross-over and mutation tasks as the magnitudes of the angles are large enough. Then in the second run as the magnitude of the angles decreases to the desirable level we applied the crossover operation. Then in the third run along with the cross over, mutation operation is also performed.

From the second run and after the third run, we are not getting the fitness values of the chromosomes better than (in decreasing trends) the fitness values obtained in the first run. So now we are accepting the whole population of chromosomes (32 chromosomes) although the population obtained from the first run is the most optimized solution for our work.

The inverse kinematics had yielded link angles based on strict mathematical model. The mathematical model fails to accommodate the effects of various internal and external parameters concerning the three link robotic arm. The angles so obtained from inverse kinematics were more theoretical in nature and less pragmatic.

The GA augmented with AHP yielded several combinations of the link angles shown as input population during various runs / iterations as given in the Tables IV, V, VI, VII.

The inverse kinematics had yielded non-optimal link angles. The GA based optimization scheme as purposed in this paper evolved various trios of local optimal and globally optimal link angles.

The success rate of GA depends upon crossover and mutation. In this work, AHP has been selected in place of conventional techniques like Roulette Wheel, Rank Selection, Steady State Selection etc.. AHP is a pragmatic method of mathematically ranking the various available alternatives (which get evolves during the execution of GA in various test runs / iterations) along with approximate reasoning.

As apparent from the simulated test results as laid in the various tables, the GA converges quickly in three runs in this case. However, the convergence may even take more test runs and thus imperiling the controllability aspect of three link manipulator movement.

VIII. CONCLUSION

It is concluded that in the presence of several optimization attributes for a physical system of higher order like three link manipulator, in this case, the GA is a practical way of finding the globally optimal solutions. Augmentation of GA with AHP reduces any chance of GA getting converted into a random search method as evident from the results obtained in this work.

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