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A Modified Biogeography Based Optimization (BBO) Algorithm for Time Optimal Motion Planning of 5 DOF PC-based Gryphon Robot

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***Abstract*—** Gryphon as a 5-DOF robot has the ability to emulate the gestures of human arm and hand. It has pivots for rotation around the elbow and wrist. The wrist has two operative pivots, for rotation and elevation. Unlike previous works which concentrate on using WALLI as Gryphon robots own software, in this paper a PC-based and XPC Target's real-time feature has been used. . Recently, techniques based on metaheuristics of natural computing, mainly evolutionary algorithms (EA), have been successfully applied to a large number of robotic applications. The aim of this paper is to evaluate a modified Biogeography-based Optimization (BBO) approach based on mutation operator to solve the trajectory planning of a Gryphon. Computer simulation results and practical experiments demonstrate that accurate trajectory tracking can be achieved by using the proposed method.

***Keywords*—** Gryphon; XPC target, Tracking Problem, PC-based, Biogeoraphy based Optimazation

I. Introduction

Over the last decade the problem of motion planning for robotic manipulators has received much attention and many researches have been done to solve this problem [1]. The tracking control of robotic manipulators has been extensively studied in recent years. The design of high performance robotic control systems, involving nonlinear control algorithms for robotic mechanisms is of much interest [2].Trajectory tracking errors for robotic system are subjected to various disturbances, such as measurement and modeling error and load variance [3]. In order to improve tracking performance the control schemes should be capable of reducing these uncertainties effects.

In this paper Gryphon as a five degree of freedom robot has been used. This robot has been performed as our case study in robotics Lab at university of Tabriz. Gryphon has the ability to emulate the gestures of human arm and hand. It has pivots for rotation around the elbow and wrist. The wrist has two operative pivots, for rotation and elevation. Many studies have been done in regards to these kinds of robots. In [4] the singularities of a five-DOF Gryphon have been studied in detail and all the singular directions are identified.

Later a method named Singularity Isolation plus Compact QP (SICQP) has been proposed to resolve the singularity problem. The most identical feature of this method is that it keeps the exactness receivable directions and minimizes the tracking errors due to the singular points at the same time. A Web-Based interface for the Gryphon robot is another example that has been done in [5]. In this paper the WWW's main aspect, i.e. communication, has been used broadly. A Web Site has been implemented that acts as a platform to control the robot.

The problem of path planning of Gryphon is to find the optimal path, between the initial and the final positions, which optimize some desired parameters. The path planning of Gryphon includes the use of kinematics and dynamics equations to obtain the joint angle combination that guide the robot to achieve desired point in the work or joint space [6]. However, the complexity of the problem may make effect on number of joints and the obstacles to be avoided, and often the problem may have multiples solutions.

Computational Intelligence techniques like genetic algorithms [7]-[8], differential evolution [9], ant colony methods [10], and particle swarm optimization (PSO) [11] have been applied to solve the challenging problems in Robotics.

Very recently a new optimization concept, based on biogeography has been proposed by Simon [12] that has showed good convergence properties on various benchmark functions. It shows the biology behavior of immigration and emigration of animal species among islands. One characteristic of BBO is that the original population is not discarded after each generation. Various versions of biogeography-based optimization modals were proposed in [13-14].

Biogeography Based Optimization (BBO) is a population-based evolutionary algorithm (EA) and it adopts the migration operator to share information among solutions. This feature makes BBO applicable to the majority of problems, where GA and PSO are applicable.

This paper evaluates adaptive genetics algorithm (AGA) and BBO, based on their convergence speed and optimal time to optimize the point-to-point trajectory planning.

The rest of this paper is formed as follows. In section 2 the features of the Gryphon robot and its practical setup is analysed. The forward and inverse kinematics of Gryphon robot have been studied in this section. The motion planning strategy is presented to describe the trajectory. The AGA and improved biogeography based optimization according to Gryphon

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constraints are described in section 3. The simulation results are shown in section 4. Finally, the paper ends with summary and conclusions.

II. Practical setup and Kinematic of gryphon robot

The five degree of freedom Gryphon robot which designed by the Walli group is shown in Fig.1. This robot has the revolute joints that simulate the gestures of the human arm and hand. The first three joints, shoulder, elbow and wrist, are used to imply the end effector to its desired position.

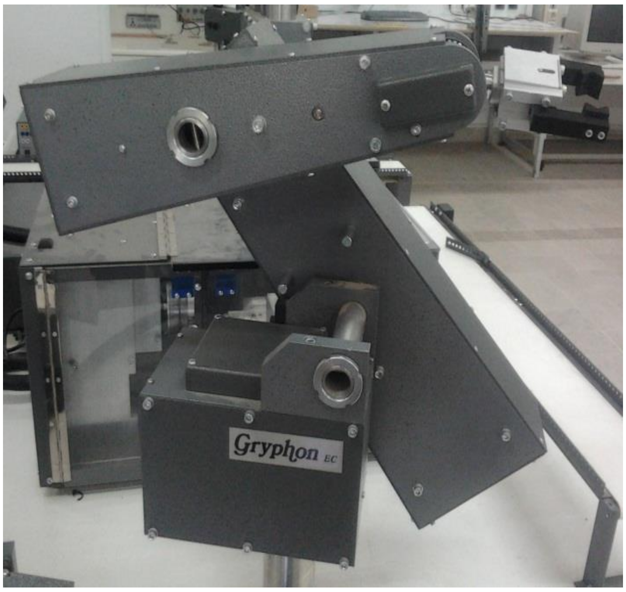

Fig. 1. The structure of Gryphon robot.

Gryphon has also a gripper which is actuated pneumatically and uses a solenoid driver for determining that whether the gripper is open or close. The end effector could be either a vacuum or a two fingered gripper. They require an air supply with a pressure of 5 to 8 bars.

All the five joints of this robot are revolute that are driven by stepper motors, and the location of each joint is derived by incremental encoders. Encoder's resolution for joints 0, 1 and 2 is 12000 steps per revolution and 2000 for joints 3 and 4. This high resolution gives a chance of precise tracking of robot. Permissible range of movement of joints 0, 1 and 2 is 270, 170 and 300 respectively. For pitch and roll axes, this range is 170 and 290.

The digital control box of this robot as shown in Fig.2, consists of four microprocessors which have their own purpose. The control circuit uses a master processor and three slave processors. One of the slave processors is used to monitor the location of the axes, two other slave microprocessors are meant to control axis motors, and the master processors is used to supervise the three other microprocessors and also to intercommunicate with the host computer.

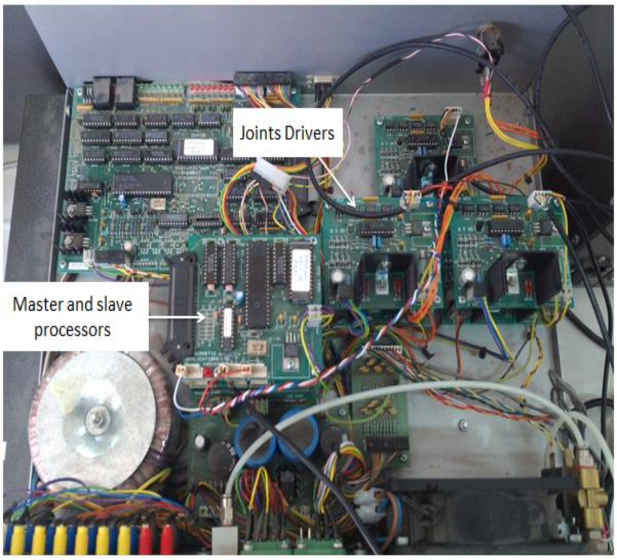

Fig.2. Digital control circuit of Gryphon robot.

The Walli operation has its own program named WALLI3 (Workcell Amalgamated Logical Linguistic Instructions), represented in Fig.3, that controls the Gryphon robot's position graphically.

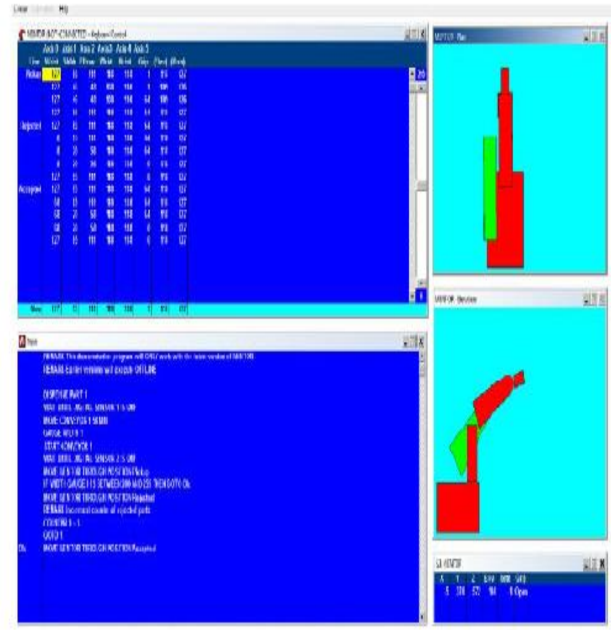

Fig. 3. WALLI Software Screen.

XPC Target has been used due to its Real-time and remote control features. In order to control the robot remotely with XPC Target two computers are needed; a Host and a Target. These two computers are connected either through serial port or TCP/IP protocol.

Gryphon has 5 drivers, and each driver requires 4 controlling signals to control the position, velocity and direction of the joints, so 20 independent controlling signals are needed.

Since the Gryphon robot has high gear ratio, so the joints could be controlled independently.

Forward kinematics of Gryphon is obtained by taking into account the physical specification. For this purpose Denavit-Hartenberg (DH) convention is used. DH parameters [15] are shown in Table 1.

Table 1. DH parameters

i	α_{i-1}	a_{i-1}	d_i	θ_i
1	0	0	Z	θ_1
2	-90	Y	X	θ_2
3	0	L2	0	θ_3
4	0	L3	0	θ_4
5	-90	0	0	θ_5
6	0	0	L4	0

Transformation matrixes are shown below:

$$ {}^{0}_{1}T = \begin{pmatrix} cos\theta_1 & -sin\theta_1 & 0 & 0 \\ sin\theta_1 & cos\theta_1 & 0 & 0 \\ 0 & 0 & 1 & z \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

$$ {}^{1}_{2}T = \begin{pmatrix} cos\theta_2 & -sin\theta_2 & 0 & y \\ 0 & 0 & 1 & x \\ -sin\theta_2 & -cos\theta_2 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \quad (1)$$

$$ {}^{2}_{3}T = \begin{pmatrix} cos\,\theta_3 & -sin\theta_3 & 0 & L2 \\ sin\theta_3 & cos\theta_3 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

$$ {}^{3}_{4}T = \begin{pmatrix} cos\theta_4 & -sin\theta_4 & 0 & L3 \\ sin\theta_4 & cos\theta_4 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

$$ {}^{4}_{5}T = \begin{pmatrix} cos\theta_5 & -sin\theta_5 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ -sin\theta_5 & -cos\theta_5 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

$$ {}^{5}_{6}T = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & L4 \\ 0 & 0 & 0 & 1 \end{pmatrix} $$

Where T_j^i shows the transformation matrix of coordinate i respect to coordinate j.

And finally we have:

$$ {}^{0}_{6}T = {}^{0}_{1}T\,{}^{1}_{2}T\,{}^{2}_{3}T\,{}^{3}_{4}T\,{}^{4}_{5}T\,{}^{5}_{6}T \quad (2)$$

III. Biogeography Based Optimization for Time-Optimal Trajectory Planning

The problem is considered as the habitat representation. For trajectory problem of Gryphon, h is the parameter to be optimized. It is encoded into individual habitat P as *suitability index variable* (SIV) with binary representation,

$$ P = (h_1, h_2, ..., h_{n-1}) \quad (3)$$

Regarding to the constraints mentioned for the Gryphon, the fitness function is defined as

$$ f_f = e_0 f_{ev} + e_1 f_{pos} + e_2 f_{velo} + e_3 f_{acc} + e_4 f_{jerk} + e_5 h \quad (4)$$

Where the constants $e_i (i = 0,1,...,5)$, are weighting factors. The functions f_{ev}, f_{pos}, f_{velo}, f_{acc}, f_{jerk} are defined as indicated in following equations, in which $v_{\max}$ is the maximum allowable velocity of the end effector in the workspace and q_i^{n+} and q_i^{n-} are the maximum and minimum possible values for *nth* derivative of q_i, respectively.

$$ f_{ev} = \begin{cases} 1 & if\ \|v\| \ge v_{max}; \\ 0 & \text{else.} \end{cases} $$

$$ f_{pos} = \begin{cases} 1 & if q_i \ge q_i^{+}; \\ & or q_i \le q_i^{-}; \\ 0 & \text{else.} \end{cases} $$

$$ f_{velo} = \begin{cases} 1 & if \dot{q}_i \ge \dot{q}_i^{+}; \\ & or \dot{q}_i \le \dot{q}_i^{-}; \\ 0 & \text{else.} \end{cases} $$

$$ f_{acc} = \begin{cases} 1 & if \ddot{q}_i \ge \ddot{q}_i^{+}; \\ & or \ddot{q}_i \le \ddot{q}_i^{-}; \\ 0 & \text{else.} \end{cases} $$

$$ f_{jerk} = \begin{cases} 1 & if q_i^{(3)} \ge q_i^{(3)+}; \\ & or q_i^{(3)} \le q_i^{(3)-}; \\ 0 & \text{else.} \end{cases} $$

In the science of biogeography, a habitat is an ecological area that is inhabited by particular plant or animal species and geographically isolated from other habitats. BBO is based on the study of the geographical distribution of biological organisms. It has some unique characteristics in compare with other evolutionary optimization methods. In fact, in BBO the problem possible solutions are identified as islands or habitats, and its operators are based on the concept of migration, to share information between the problem solutions. Four new parameters are introduced in BBO: *suitability index variable* (SIV) represents a variable that characterize habitability in an island, i.e. in a solution; *habitat suitability index* (HSI), represents the goodness of the solution, similarly to the fitness score concept in GA; *immigration rate* (λ) indicates how likely a solution is to accept features from other solutions; *emigration rate* (μ) indicates how likely a solution is to share its features with other solutions. A low suitable habitat has a low emigration rate and high immigration rate. High performing solution has a high emigration rate and low immigration rate, in fact, when HIS increases, the number of species grows, the habitat where becomes more crowded, and more species are able to leave the island to explore other possible habitats, thus the emigration increases. SIVs are the independent variables while HSI are the dependent variables.

Habitats with high HSI have the large population and high emigration rate. The immigration rate λ is low for those habitats which are already saturated with species. On the other hand, habitats with low HSI has high immigration rate λ due to sparse population. For low HIS habitats, the value of HSI, may increase with the immigration of species from other habitats. However, if HSI does not increase, species in that habitat go extinct and this leads to additional immigration. It is reasonable to use a linear relationship between habitats HSI, its immigration and emigration rate. These rates are same for all the habitats in BBO method.

Fig. 4 depicts the relationship between fitness of habitats and emigration rate μ and immigration rate λ .

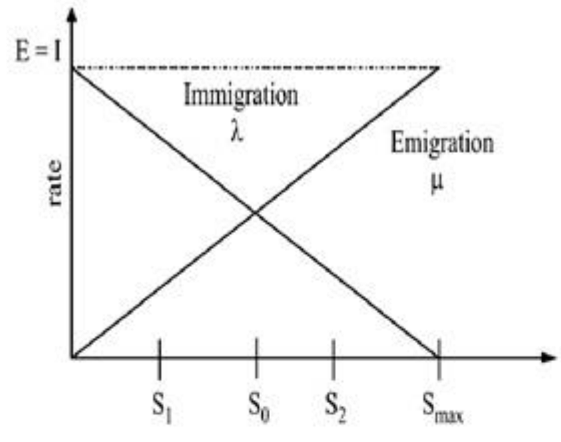

Fig. 4. Model of species in BBO algorithm[12]

In this figure E is the maximum value of emigration rate and I is the maximum value of Immigration rate. S is the number of species in each habitat. S_{max} and S_0 are the maximum number of species and the equilibrium value respectively. It is obvious that in $S = S_0$ the immigration and emigration rates are equal.

High HSI solutions tend to share their features with low HIS solutions. Poor solutions accept the new features from valuable solutions. In BBO, a population of valuable solutions is shown as vectors of integers. Each integer in a solution vector is considered to be a SIV.

In BBO, each habitat has its own emigration rate λ_k and immigration rate μ_k that can be calculated by following equations [9]:

$$\lambda_k = \frac{Ek}{P} \qquad (5)$$

$$\mu_k = I(1 - \frac{k}{P})$$

P is individual number and k is the number of habitat.

Improved BBO algorithm in which the probable mutation method is used at step 8 is as follows:

1- Producing some stationary habitats and ordering them. Each habitat should have a emigration and immigration rate.

2- Defining λ, μ according to habitats rank

3- For each habitat like I do the steps 4-8

4- For each integer like k in ith habitat do the steps 5-8

5- With probability of λ_i in x_{ik} do the steps 6-8

6- Selecting the destination of emigration according to value of μ and called it j.

7-Doing emigration from x_{jk} to x_{ik}

8- Applying mutation operation on components of x_{ik} with the probability of α

9- Evaluating the new habitats

10- Replacing the new habitats with old ones and producing the modified habitats.

11- If the final criteria does not satisfied return to step 4.

In fact step 3-8 lead to change in I,4-8 cause a change in k and 5-8 shows the manner of changes. The flowchart of algorithm is presented in figure 5.

IV. SIMULATION

Parameter values for practical Gryphon robot are:

X=18mm: The second link offset to left from base.
Y=50mm: The second link offset to front from base.
Z=366mm: The first joint height from base.
L2=225mm: The length of second link (shoulder).
L3=225mm: The length of third link (elbow).
L4=16.3mm: Distance between fifth and sixth frame.

The results of the simulation are presented in this section. The initial and final points for the Gryphon are respectively selected as $q_0 = [0.1, 0.3, 0.2, 0.1, 0]$ and $q_f = [0.2, 0.3, 0, 0, 0]$.

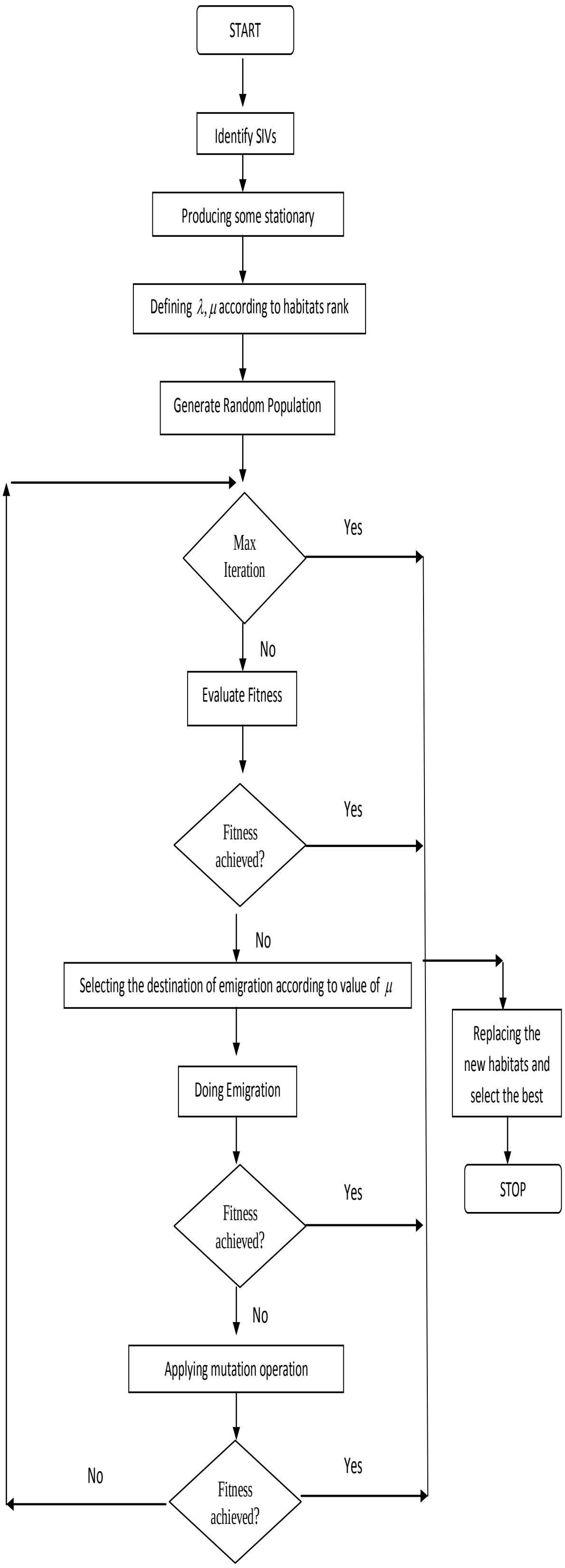

Fig. 5. Flowchart of proposed Algorithm

Time is quantized between 0.01 and 50 with 16 bits.

Initial and final joint velocities are also defined as $v_0 = [0, 0.1, 0, 0, 0.2]$, $v_f = [0, -0.3, 0, 0, 0.4]$.

For the biography based optimization method maximum number of iterations and number of habitats are chosen 100 and 50 respectively. Keep rate is 0.2. To choose emigration and Immigration rates the following method is used:

Emigration rate=linspace(1,0,50)

Immigration rate=1-Emmigration rate

α and the coefficient of mutation are chosen 0.9 and 0.1 respectively. Roulette wheel is used as our selection method.

e_0, e1, e2, e3, e4, e5 respectively are set to 1000, 100, 10, 10, 0.2 because obviously violating displacement is more important than violating jerk or acceleration.

Fig. 6 is depicted convergence plots of optimal time for tournament selection method to show the effectiveness of the time-optimal trajectory planned by AGA.

Simulation results indicate that even by using adaptive genetic algorithm and tournament selection method the answer will be found in around 45 generations and will be 3.1s which is not desirable.

Fig. 7 is depicted convergence plots of optimal time for Biogeography based optimization to show the effectiveness of the time-optimal trajectory planned by that. Result for improved BBO method is presented in Fig. 8.

Using improved BBO described above and constraints data that were mentioned, the optimal trajectory is found in 12th generation and will be 1.37s.

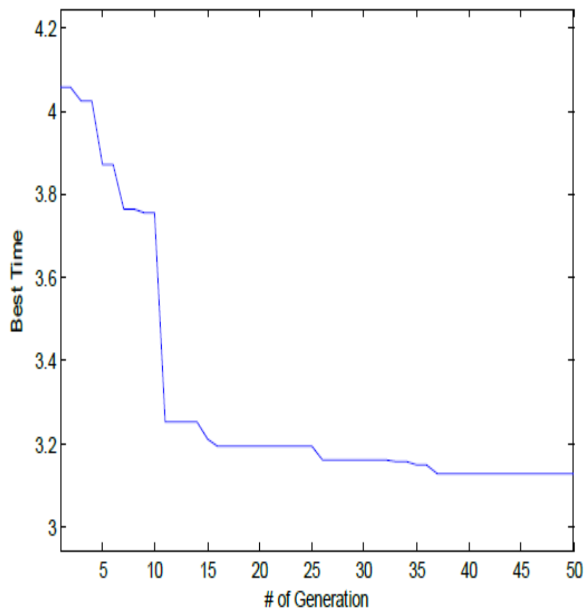

Fig. 6. Convergence plot of optimal time using Adaptive Genetic Algorithm

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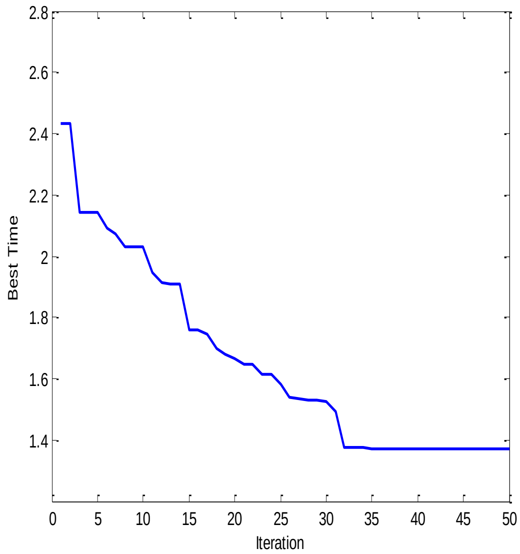

Fig. 7. Convergence plot of optimal time using BBO algorithm

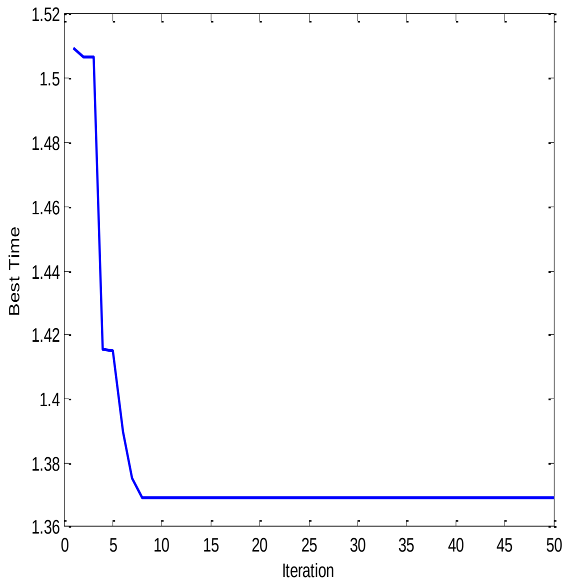

Fig. 8. Convergence plot of optimal time using improved BBO algorithm

V. CONCLUSION

In this paper a novel PC-based and XPC Target's real-time feature has been used due to its real-time and remote control properties. In order to control the robot remotely with XPC Target two computers named Host and Target are connected through serial port with TCP/IP protocol.

A modified biogeography based optimization (BBO) algorithm as a global search optimization technique was implemented to time-optimal trajectory planning for a Gryphon manipulator. This technique proved its capability to produce an optimized minimum-time trajectory in the presence of several constraints. Simulation results indicate that with using adaptive genetic algorithm the answer will be found around 38 generation and will be 3.1s, which is not desirable. By using BBO and improved BBO, it converges in around 32 and 9 generations respectively that is acceptable and compared with the simulation results of path planning based on adaptive genetic algorithm it has less trajectory time but higher performance. From the results of simulation, it is concluded that proposed method can significantly raise the efficiency of the robot.

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