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Grasshopper Algorithm based Fuzzy system for Trajectory Tracking of Robot Manipulator

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Abstract– This work presents a grass hopper optimization algorithm based fuzzy system for trajectory following in robot manipulators. The idea is to optimize the parameters of the fuzzy control scheme . The modified copy of the algorithm is presented and adopted in the optimization process of parameters of fuzzy controllers. The developed modified grasshopper based fuzzy scheme is applied for trajectory tracking in two link robot manipulator and compared with that of using the basic grasshopper optimization algorithm. Simulation. Results show good tracking performance for the new developed scheme.

Keywords— Grasshopper optimization algorithm; Fuzzy system; Metaheuristic ; Robot manipulator; Trajectory tracking.

I. INTRODUCTION

It is very common that robot manipulators are complicated and nonlinear systems. It is widely used in welding , painting and accurate positioning systems . Manipulators are required to follow some given trajectories in many applications. Trajectory tracking is an important concept in robotic manipulators and it was considered in many research works. A conventional proportional, integration, derivative (PID) controller was adopted in [1]. In [2] a nonlinear feedback strategy was adopted. An adaptive control concept was used in [3]. A tracking control of manipulators using sliding surface was presented in[4], fuzzy control for tracking enhancement was adopted [5],[6] . Fuzzy controllers are widely used in different applications[7]-[11].

Authors in [12] presented a fuzzy controller combined with pole placement technique for the control of a robot manipulator . The fuzzy controller was designed to modify the components of the controller for the purpose of elimination of the effects of the change in payload and the parameters of the system .

An adaptive fuzzy mechanism approach is proposed for motion following in [13]. The Bacterial Foraging algorithm is used for the determination of fuzzy controller for motion tracking and compared with Particle Swarm Optimization algorithm [14] A fuzzy position control scheme designed for a three-link manipulator in [15]. Simulation results are presented which indicate good tracking performance. Authors in [16] presented the design of an optimal linear quadratic regulator based on using fuzzy controller and applied it for the robot manipulator . The stability analysis was presented. In [17] a combined control scheme of PD-type fuzzy controller with a conventional PID is used for trajectory following of robot manipulator .

The grasshopper algorithm (GOA) is a new optimization algorithm that was inspired from movements of grasshoppers in groups[18]. Many works have been presented that used GAO in different applications[19]-[21] . Several authors propose to modify the GOA[22]-[24].

In this article an optimal control scheme is designed using a modified grasshopper optimization algorithm and was compared with that using the basic GOA . The aim of this work is the presentation of a modified GOA based on using chaotic initial population and study the performance of chaotic GOA and compare it with the basic GOA.

The rest of the article is arranged as: Equations of robot manipulator were presented in section2. Section3 contains introduction to fuzzy controller . The grasshopper algorithm is presented in part 4 . Part 5 is for the results and the conclusion is presented in the last part.

II. ROBOT MANIPULATOR MODEL

The dynamical equation of n-link robot manipulator is [25]:

$$M(q)\ddot{q} + B(q,\dot{q})\dot{q} + G(q) + f(t) = U \qquad (1)$$

Where q is $n \times 1$ joints displacement , U is $n \times 1$ applied joint torque , $M(q)$ is $n * n$ inertia matrix, $B(q,\dot{q})\dot{q}$ is $n \times 1$ centrifugal term, $G(q)$ is $n \times 1$ gravitation vector, and $f(t)$ is $nx1$ disturbance vector.

The dynamic equation for the two links manipulator illustrated in Fig.1 is:

$$\begin{bmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{bmatrix}\begin{bmatrix} \ddot{q}_1 \\ \ddot{q}_2 \end{bmatrix} + \begin{bmatrix} B_{11} & B_{12} \\ B_{21} & B_{22} \end{bmatrix}\begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \end{bmatrix} + \begin{bmatrix} G_1 \\ G_2 \end{bmatrix} = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \quad (2)$$

Where:

$$M_{11} = (m_1 + m_2)l_1^2 + m_2 l_2^2 + 2m_2 l_1 l_2 \cos(q_2) + J_1$$

$$M_{12} = M_{21} = m_2 l_2^2 + m_2 l_1 l_2 \cos(q_2)$$

$$M_{22} = m_2 l_2^2 + J_2 \ , \ B_{11} = -2m_2 l_1 l_2 \dot{q}_2 \sin(q_2)$$

$$B_{12} = -m_2 l_1 l_2 \dot{q}_2 \sin(q_2) \, , B_{21} = -2m_2 l_1 l_2 \dot{q}_2 \sin(q_1)$$

$$B_{22} = 0$$

$$G_1 = ((m_1 + m_2) l_1 m_2 \cos(q_1) + m_2 \, l_2 \cos(q_1 + q_2))g$$

$$G_2 = (m_2 \, l_2 \cos(q_1 + q_2))g$$

The mass of the first link is m_1 and that of the other is m_2. The angle of the first link is q_1 and that of the other is q_2. The length of first link is l_1 and that of the other link is l_2. The control signal for the first link is u_1 and that of the other link is u_2

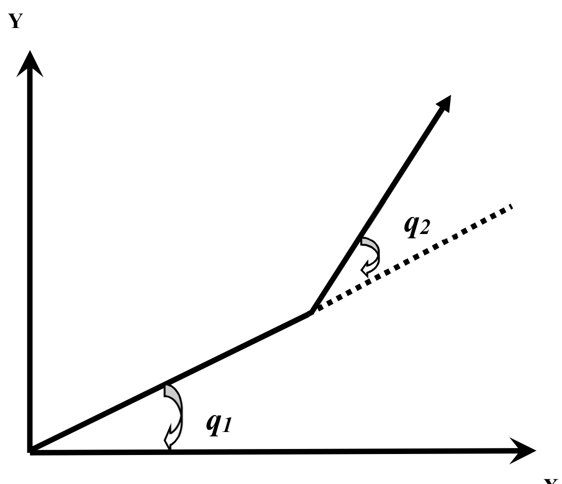

Fig. 1. Two-Link robot manipulator

III. FUZZY CONTROLLER

Fuzzy control system is used in many applications. The basic concept of fuzzy controller is illustrated in Fig.2. It consists of four stages : fuzzification, inference engine, rule base and defuzzification.

In this work MGOA is used for modifying parameters of fuzzy controllers. In this work a fuzzy controller is used for each link. Each controller has two inputs and one output . The inputs are the error in position and the derivative of error. The output is the control variable. The membership functions for the input variables were selected to be symmetrical about the y-axis.

Seven fixed and equally spaced triangular membership functions are utilized for input variables as we see in Fig.3. The input membership functions shown in Fig.3 consists of three positive (big , middle and small) , one zero membership function and three negative (small, middle and big). The seven output membership functions are to be optimized using MGOA.

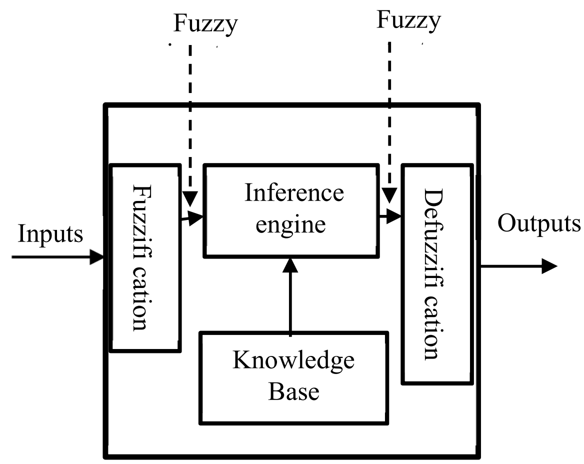

Fig. 2. Fuzzy controller

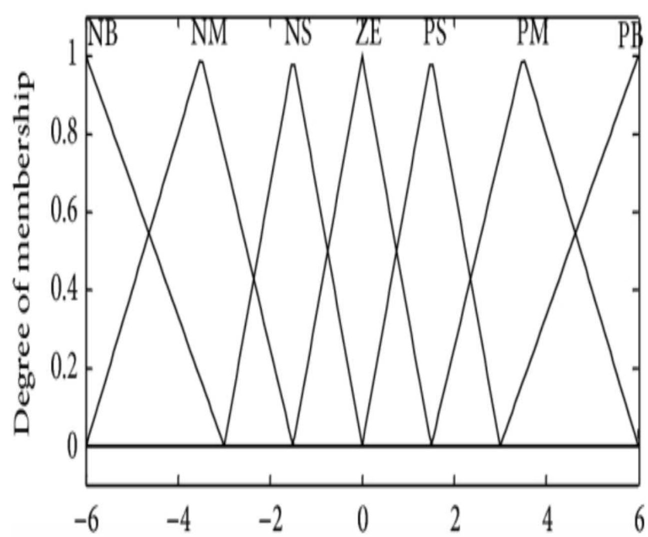

Fig. 3. Membership function of Inputs

IV. BASIC GRASSHOPPER ALGORITHM

The grasshopper algorithm (GOA) was inspired from movements of grasshoppers in groups . A mathematical model was proposed to describe the behavior and relations between grasshoppers in groups. . The model was illustrated as follows[18] :

$$x_i = S_i + G + A_i \qquad (3)$$

where x_i is the location of grasshopper i, S_i is the relations in a group, G is the gravity force. A is the direction of wind . Equation (3) can be expressed as in(4) :

$$x_i = \sum_{j=1, j\neq i}^{N} s\left(\left[x_j - x_i\right]\right) \frac{x_j - x_i}{d_{ij}} - g\hat{e} + ue_w \qquad (4)$$

Where

$$S(r) = fe^{r/l} - e^{-r} \qquad (5)$$

is a function that show the effect of relations. N is the number of grasshoppers.

and , $A_i = ue_w$; $G = g\hat{e}$.

where g is the gravitational constant and $\hat{e}$ is a unit vector. The letter u is a constant drift and e_w is a unit vector , d_{ij} is the distance.

$$d_{ij} = \left|x_j - x_i\right|$$

The effects of wind and gravity are small and can be neglected [18] . The model in equation (4) can be modified as in equation(6) below:

$$x_i = c\left(\sum_{j=1, j\neq i}^{N} c \ \frac{ub-lb}{2} s\left(\left[x_j - x_i\right]\right) \frac{x_j - x_i}{d_{ij}} + \hat{T}d \qquad (6)$$

where ub and lb are boundaries of the space, $\hat{T}d$ is the best solution , and c is a decreasing factor defined as follows:

$$c = c_{max} - iter \frac{c_{max} - c_{min}}{Max_{iter}} \qquad (7)$$

where $c_{\max}$ is equal to 1 and $c_{\min}$ is equal to 0.00004. The variable iter is adopted for the current iteration. The constant Max_{iter} indicates the maximum number of iterations.
In the basic GOA the initial population is selected randomly. In this work the selection method is replaced by using chaotic function . The initial population is generated using chaotic function:

$$xc(\mathrm{i}+1) = 4\, xc(\mathrm{i}) * \left(1 - xc(\mathrm{i})\right) \qquad (8)$$

Then convert xc to x , a chaotic quantity in the range $[x_l \quad x_h]$ using (9):

$$x(\mathrm{i}) = x_l + xc(\mathrm{i})(x_h - x_l) \qquad (9)$$

V. SIMULATION RESULTS

The aim of the experiment is to test the performance of the proposed control scheme . The robot manipulator shown in Figure 1 is considered. It has two links. Parameters values for 2-link robot manipulator are from [25].

Length of upper link (l_1) = 1m.

Length of lower link (l_2) = 0.8m.

Mass of upper arm (m_1) = 0.5kg.

Mass of lower arm (m_2) = 0.5kg.

The inertia of two joints ($J_1 = J_2$) = 5kg.m^2.

To simulate the above robot manipulator model, Matlab and Simulink are used. The search space consists of 14 dimensions, seven dimensions specified for the first fuzzy controller which represent the centers of output membership functions and seven dimensions for centers of output of the second fuzzy controller . The MGOA initial values are illustrated in Table 1 .

The proposed control scheme for the 2-link robot manipulator consists of two controllers one for each link. The rule base is shown in[11]. The trajectories are chosen as the cubic polynomials generated based on the following functions:

$$q_{d1} = a_{01} + a_{11}t + a_{21}t^2 + a_{31}t^3$$
$$q_{d2} = a_{02} + a_{12}t + a_{22}t^2 + a_{32}t^3$$

TABLE I: MABC initial values

Parameter	Value
Size of population	50
Maximum iteration	80
Dimension	14
c_{max} , c_{min}	1 , 0.00004

where

$$a_{01} = a_{11} = 0;\ a_{21} = 0.0937;\ a_{31} = -0.01562$$
$$a_{02} = a_{12} = 0\ ;\ a_{22} = 0.75,\ a_{32} = -0.125$$

The assumed desired final positions q_{1f} = 0.5 rad and q_{2f} = 4 rad for each link at the final time (t_f= 4 sec) .

The initial positions (q_1=q_2=0).The initial and final velocities are equal to zero.

The fitness function chosen is the mean square error (MSE):

$$fitness = \frac{1}{N}[\sum_{i=1}^{N} e1_i^2 + \sum_{i=1}^{N} e2_i^2]$$

$$e1 = q_{d1} - q_1$$

$$e2 = q_{d2} - q_2$$

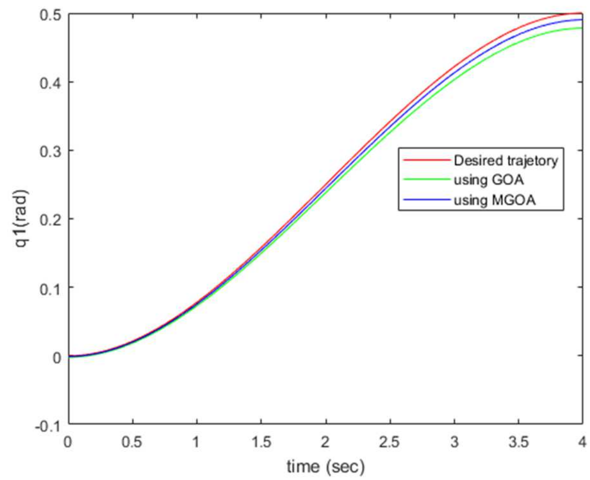

Fig.5. Response q_2 for both methods

The presented results were done based on six trials for each method . The best results for both methods are presented . Fig.4 shows the trajectory q_1 for both methods. Fig.5 shows q_2 for both methods. Fig.6 illustrates the error in q_1 and Fig.7 for the error in q_2 . Clearly results show some improvement when MGOA is used.

The best MSE =0.0086 for GOA . For MGOA the best MSE =0.0039 ; Average MSE=0.0092 for GOA . For MGOA the average MSE =0.0059.

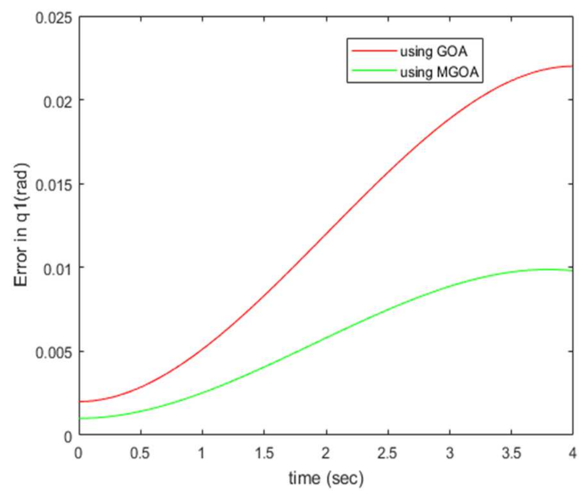

Fig. 6. Error in q_1 for both methods

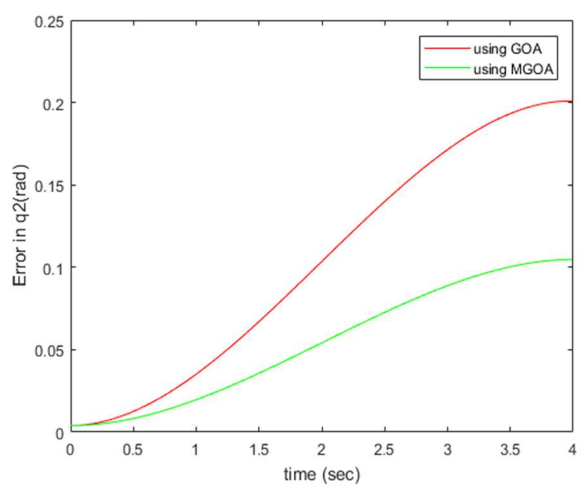

Fig.7. Error in q_2 for both methods

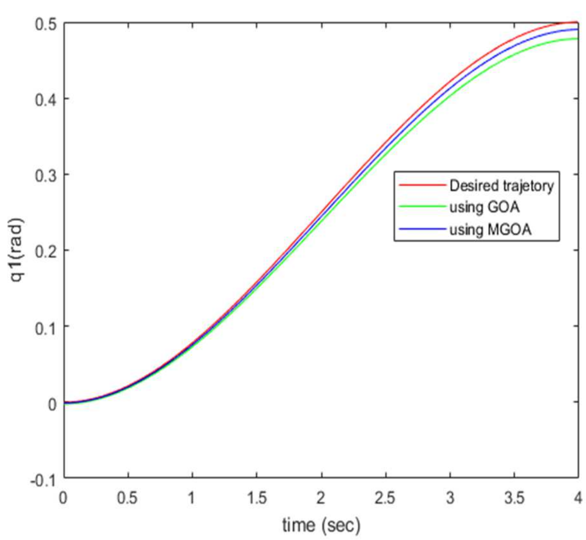

Fig. 4. Response q_1 for both methods

VI. CONLUSIONS

In this work, the modified GOA based fuzzy control scheme is applied for trajectory following of two link robot manipulator. Two design methods are considered one is based on using the basic GOA and the other is based on using the modified GOA controller. The test is repeated six times. The best result show good performance for both method . The average fitness is also good in both method. In general there is no big difference between them and the MGOA show better results in most trials . The work may be extended to further study the performance of GOA.

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