Mobile Robot Path Following Using Chaotic Grasshopper Algorithm based Fuzzy Control Approach

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***Abstract*— This paper presents an optimal fuzzy control approach for mobile robot path tracking. The modified chaotic grasshopper optimization algorithm was presented with an explanation of the method of using it to determine the best values for the design parameters. It is applied for path tracking of mobile robot and a comparison was made with the results of the basic algorithm. The experiment was conducted seven times. Results of the modified scheme offer better achievement**

Key words: Fuzzy control; CGOA; Mobile robot; Path following

I. INTRODUCTION

Fuzzy logic has been extensively used in various fields. [1-3]. It is used as a controller in different applications [4-8]. The control of mobile robot has been considered in many works [9-12]. In general, fuzzy controller is suitable for controlling nonlinear dynamic systems. Many optimization methods have been considered to be used in the design of fuzzy controller. Several works consider using genetic algorithm for different control applications [13,14]. In many works the particle swarm optimization has been adopted to optimize fuzzy controllers for various applications [15-19]. The artificial bee colony algorithm has also been adopted in designing optimal fuzzy controller for different applications [20-24] The Grasshopper optimization algorithm (GOA) is a new optimization method. It was prepared to represent the behavior of grasshopper in groups [25]. Many works have been conducted on this algorithm in different fields [26-28] Several works have presented suggestions for modifying the basic grasshopper optimization algorithm [29-33]. The purpose of the presented work is to use a modified Chaotic Grasshopper Optimization Algorithm (CGOA) that uses an initial population generated by a chaotic function to study the effect of this modification and to compare it with the original algorithm. The remaining parts are arranged as: The basic is presented in the second part. The design method is explained in part three. Results are presented in part four. The conclusions are presented in part five.

II. BASIC PRINCIPLE

A. MATHEMATICAL MODEL

Generally, the model consists of two parts, the first part is related to the movements and is used at low speeds, low load and weak acceleration, and is described by equation (1) [19]

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$$\begin{bmatrix} v \\ \dot{\varphi} \end{bmatrix} = 1/2 \begin{bmatrix} r & r \\ r/b & -r/b \end{bmatrix} \begin{bmatrix} w_r \\ w_l \end{bmatrix} \quad (1)$$

Where v and φ represent the velocity and azimuth of the robot , r is radius , b is half the space between wheels, w_l and w_r are the speeds of left and right wheels, respectively.

The second part represents the dynamic model. Fig.1 offers a simplified diagram.

Define a state vector as $x = [v \;\; \varphi \;\; \dot{\varphi}]^T$, output as y=$[v \quad \varphi]$ and input vector as $u = [u_r \;\; u_l]^T$.

The general model:

$$\dot{x} = Ax + Bu \quad , \quad y = Cx \quad (2)$$

Here,

$$A = \begin{bmatrix} a_1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & a_2 \end{bmatrix}, \quad B = \begin{bmatrix} b_1 & b_1 \\ 0 & 0 \\ b_2 & -b_2 \end{bmatrix},$$

$$C = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \text{ with,}$$

$$a_1 = \frac{-2z}{(mr^2+2I_w)}, \quad a_2 = \frac{-2zl^2}{(I_v r^2 + 2I_w l^2)},$$

$$b_1 = \frac{kr}{(mr^2+2I_w)}, \quad b_2 = \frac{krl}{(I_v r^2 + 2I_w l^2)}$$

The variables I_v, I_w are the inertia of robot and wheel respectively. The variable m refers to the mass, the variable l is the space between wheels, and the variable z is the friction.

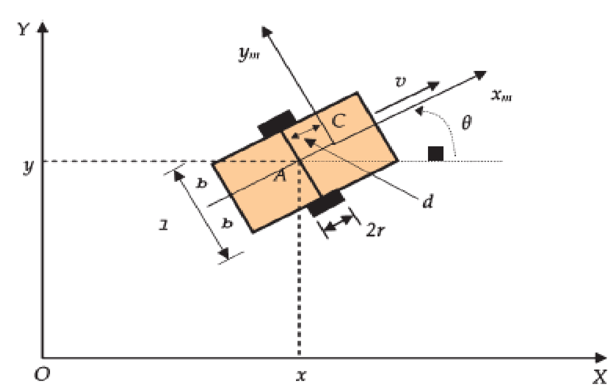

Fig.1 A simplified diagram

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B. *Grasshopper Optimization Algorithm*

GOA is a mathematical simulation of grasshopper movements. This model can be interpreted as: [25]

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

Here, x_i represents the position of individual i, and S_i represents the relationships. G represents the gravity, and A_i represents the wind. The equation can be written as:

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

Where

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

This function is employed to exhibit relations impact. Here f is the pull force and l is the pull range. N is the number of individuals.

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

Here, g represents the gravity coefficient, $\hat{e}$ and e_w are unity vectors, and u is a constant , and d_{ij} represents distance.

$$d_{ij} = |x_j - x_i|$$

It can be simplified as shown below [25]

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

The variables lb and ub represent the ends, and the variable $\hat{T}d$ represents the best solution, while the variable c represents a reducing factor and is defined by :

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

The value of c_{max} is 1 and the value of c_{min} is 0.00004 [25]. The variable $iter$ is used as a counter. While the constant Max_{iter} is used to indicate the upper number. In the original GOA algorithm, the first population is chosen randomly. A chaotic function is used here to generate the first population as:

$$cp(n+1) = 4\,cp(n)\,(1 - cp(n)) \qquad (8)$$

And cp is converted to x using (9) , here x is a chaotic quantity in the designed range from x_l to x_h :

$$x(n) = x_l + cp(n)\,(x_h - x_l) \qquad (9)$$

III. MODIFIED CGOA BASED FUZZY CONTROL APPROACH

In this approach, the CGOA is used to optimize fuzzy controllers. Each individual in CGOA represents the parameters of controllers.

Seven MFs are selected for each variable (symmetrically about the vertical axis). Centres of the MFs are taken as design parameters (three centres for each variable). The control approach is illustrated in Fig. 2 (two controllers each with two inputs and one output, namely speed controller and direction controller).

The error in speed is

$$e_v = v_d - v \qquad (10)$$

And assume the derivative of error as ed_1

The error in direction is

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$$e_\varphi = \varphi_d - \varphi \qquad (11)$$

and assume the derivative of error as ed_2.

v_d , φ_d are the required values of velocity and azimuth.

The torques u_r and u_l are given by :

$$u_r = o_1 + o_2$$

$$u_l = o_1 - o_2$$

Where o_1 and o_2 are the outputs of the two controllers as in Fig. 2.

Seven Member Functions (MFs): Negative Massive (NM), Negative ordinary (NO), Negative Weak (NW), Zero (Z), Positive Weak (PW), Positive Ordinary (PO), and Positive Massive (PM) are assigned to every variable. Weighted average procedure is adopted to calculate the outputs of both controllers. Both fuzzy controllers are optimized by the CGOA algorithm. The population includes N individuals as: $[\, I^1\, I^2 \ldots I^N \,]$.

Here, N= 50.

Symmetric MFs are selected so that only the center values are considered. Each individual in the CGOA algorithm is a vector of 14 items as:

$$[\, I_1^k \; I_2^k \; I_3^k \; I_4^k \; I_5^k \; I_6^k \; I_7^k \; I_8^k \; I_9^k \; I_{10}^k \; I_{11}^k \; I_{12}^k \; I_{13}^k \; I_{14}^k \,]$$

IV. SIMULATION RESULTS

The suggested control approach is shown in Fig. 2. The values of I_v and I_w are 10 Kg. m^2 and 0.005 Kg. m^2 respectively. The value of m is 200 kg, r and l are 0.1 m, 0.3 m respectively and z is 0.05 Kg/s. [25].

The robot is examined in following a circular path to study how the proposed control approach performs in guiding the robot to follow the desired path.

The required speed is v_d = 0.3 m/s and the required azimuth is

$$\varphi_d = (-2\pi * t/5) \text{ rad},$$

where $0 \le t \le 5$

and the sampling period is 0.01 sec. In the experiment, the robot initial position is [x0, y0, ϑ0] = [0.3 m, 0 m, 0 rad]. Table 1 presents rules.

The fitness function *fit* is selected as:

$$fit = \frac{1}{M}\left[\sum_{i=1}^{M} e_{1_i}^{2} + \sum_{i=1}^{M} e_{2_i}^{2}\right] \quad (12)$$

Fig.3 presents the fitness for GOA and CGOA. The errors are presented in Fig. 4 and 5. It is clear that the presented CGOA shows better results.

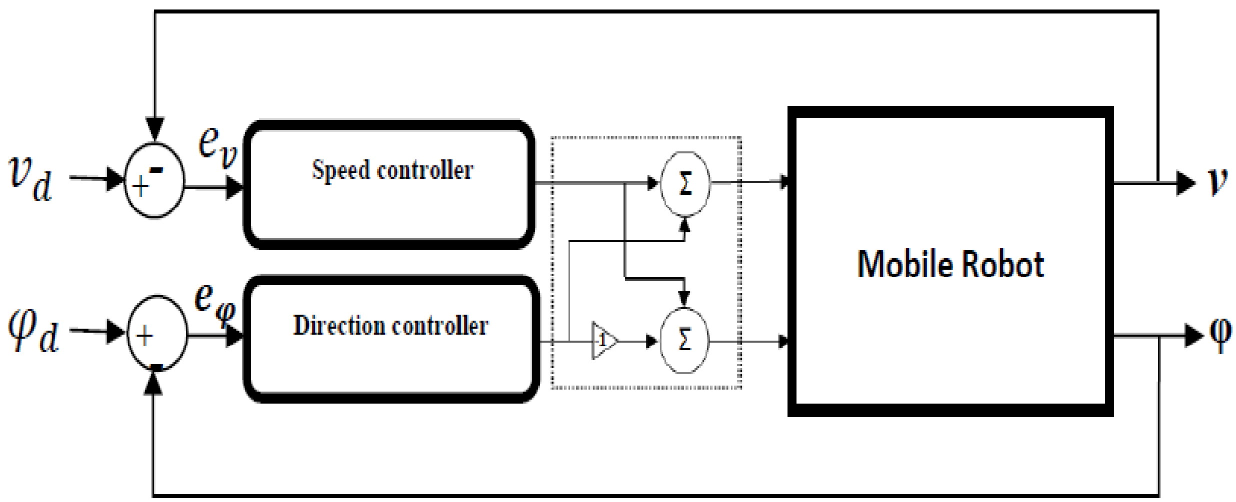

Fig. 2 Control approach

Table 1 Rule base for the fuzzy control

e/ed	NM	NO	NW	Z	PM	PO	PW
NM	NM	NM	NM	NM	NO	NW	Z
NO	NM	NM	NM	NO	NW	Z	PW
NW	NM	NM	NO	NW	Z	PW	PO
Z	NM	NO	NW	Z	PW	PO	PM
PW	NO	NW	Z	PW	PO	PM	PM
PO	NW	ZE	PW	PO	PM	PM	PM
PM	Z	PW	PO	PM	PM	PM	PM

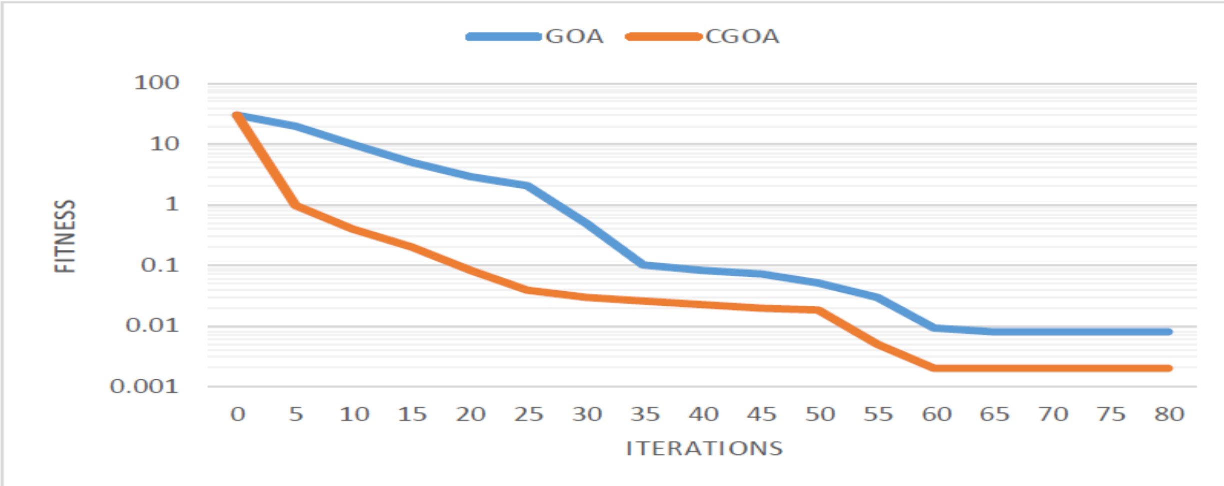

Fig.3. The fitness

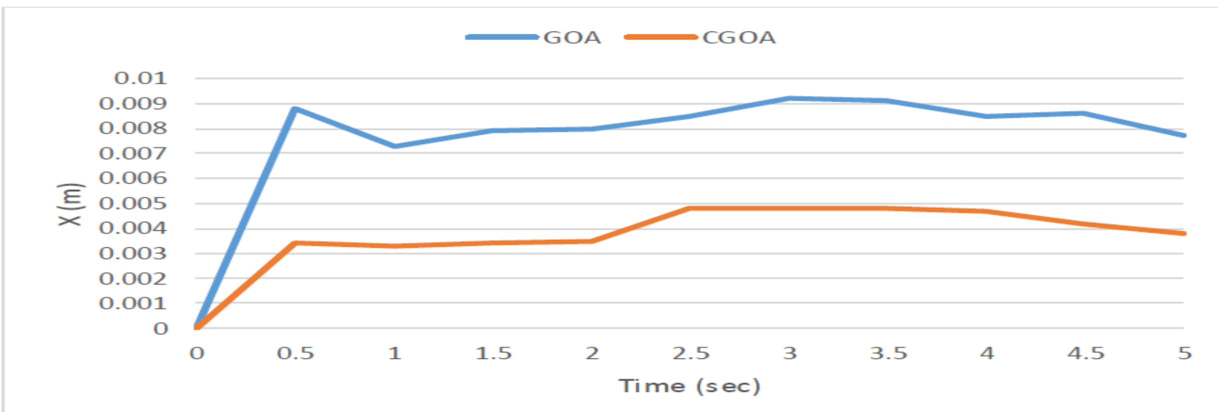

Fig. 4 Error in x(t)

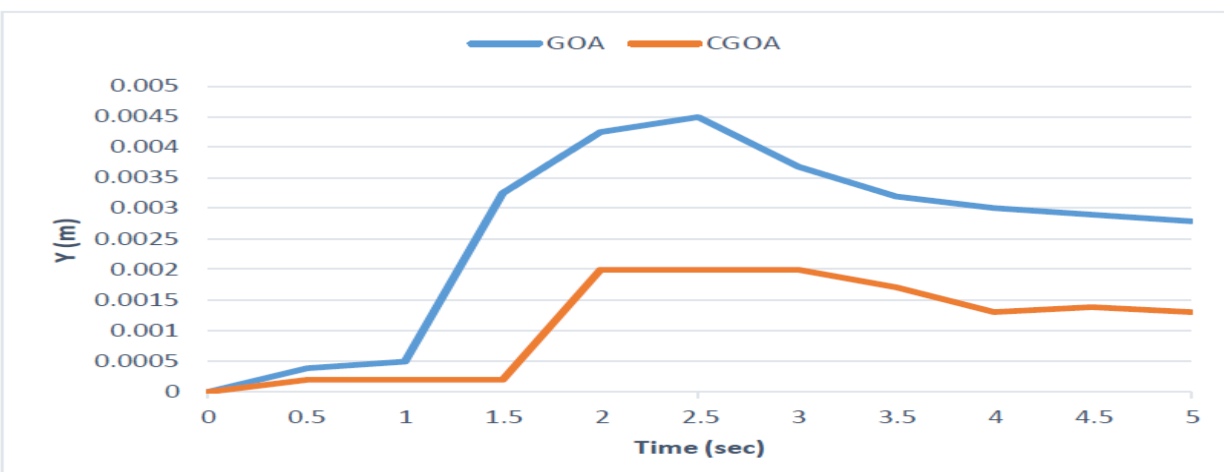

Fig. 5 Error in y(t)

V. CONLUSIONS

The modified CGOA algorithm was proposed and used to design an optimal fuzzy control approach for path following. For comparison, the test was conducted seven times, and the results showed good performance for both methods. However, the modified CGOA-based approach showed better results in most of the experiments. In fact, further analysis is needed to explore the effect of this modification on convergence speed, exploration, and other important properties.

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