

Optimal PID controller design using artificial bee colony algorithm for robot arm

Ghassan A. Sultan, Muhammed K. Jarjes

Northern Technical University, Technical Engineering College, Department of Medical Instrumentation Technical Engineering, Mosul, Iraq

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ABSTRACT

Proportional integral derivation (PID) controller is used in this paper for optimal design, and tuning by zeigler and nichol (ZN) with artificial bee colony algorithm. The best parameter were found using these algorithms for best performance of a robot arm. The advantage of using ABC were highlighted. The controller using the new algorithm was tested for valid control process. Different colony size has been performed for tuning process, settling time, from time domain performance, rise time, overshoot, and steady state error with ABC tuning give better dynamic performance than controller using the (ZN).

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Corresponding Author:

Ghassan Ahmed Sultan

Department of Medical Instrumentation Technology Engineering

Northern Technical University

Mosul, Iraq

Email: ghassankassab@ntu.edu.iq

1. INTRODUCTION

Generally, the body of a robot has a range of joints. Ignoring the effect of joints movements, the servo mechanism is used in the designing process the control of the arm joints. The hydraulic or gas actuator for industrial robot are used instead of dc servomotor. Due to their high speed in position management characteristic, the DC motors are widely used in the field of trade. The mechanism is normally associate with the armature control motor. The robot arm should be connected to the motor via a gear system [1]. Using proportional integral derivative (PID) controller for controlling speed and location of the robot arm. The objective of this research is to design a system exploitation artificial bee colony optimization (ABC). To optimize the gains, ABC algorithm is employed leading to application of the value into the controller of the plant. The gains of the PID controller are optimized by the logarithm for a given plant. Thus the error is detected by the controller depending on the proportional gain, whereas elimination of steady state error and stop over shoot is facilitated by the integral derivative gain [2-4]. Using ABC formula algorithm to perform the calibration and the controller leading to evaluation of the optimum controller on each occasion [5, 6]. This indicates that the system performance optimum calibration can be reached using exploiting the ABC technique. The result of the ABC ultimate system with classical tuned system [7, 8].

2. MATHEMATICAL MODEL OF ROBOT

Hardness and gravity has no effect on the arm of the robot as shown in Figure 1 [9]. Figure 2 shows the robot joint system [10, 11]. The dynamic movement of the system in the arm is shown in the following equations [12, 13].

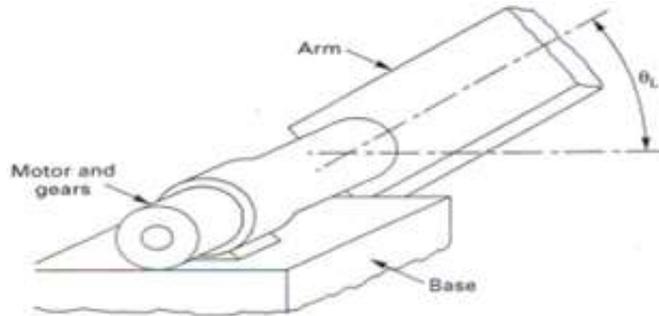


Figure 1. Typical one-joint robot arm

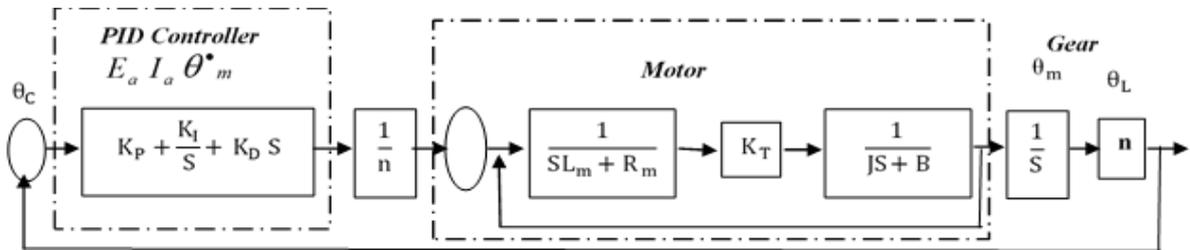


Figure 2. Control system in a robot joint

$$e_a(t) = e_m(t) + R_m i_a(t) + L_m \frac{di_a(t)}{dt} \tag{1}$$

$$e_m(t) = K_m \frac{d\theta_m(t)}{dt} \tag{2}$$

$$T_m = K_T I i_a(t) \tag{3}$$

$$T_m = B \frac{d\theta_m(t)}{dt} + J \frac{d^2\theta_m(t)}{dt^2} \tag{4}$$

$$T_m = n^2 J l + J_m \tag{5}$$

$$B = n^2 B l + B_m \tag{6}$$

$$\theta_L = n \theta_m \tag{7}$$

The equations simplified and get the ratio of $\frac{\theta_L(S)}{E_a(S)}$ so the transfer function will be getting as follow:

$$\frac{\theta_L(S)}{E_a(S)} = \frac{n K_T}{L_m J S^3 + (J R_m + B L_m) S^2 + (K_m K_T + B R_m) S} \tag{8}$$

where.

R_m is the resistance of armature- winding (Ohm (Ω))

i_a is the current of armature-winding (Ampere (A))

L_m is the armature-winding inductance (Henry (H))

e_m is the back emf voltage (Volt (V))

T_m is the motor torque (N.M)

K_m is the back emf constant (volt/(rad/sec))

K_T is the constant of motor torque (N.m/A)

J is the motor and robot arm moment of inertia (kg/rad)

θ_m is the motor shaft angular displacement (rad)

θ_c is the reference input angular displacement (rad)

θ_L is the robot arm angular displacement (rad)

B is the motor and robot arm viscous-friction coefficient (N.m/rad/sec)

N is the ratio of the gear (N_1/N_2).

The following parameters represent the robot arm control system: $J=2$ kg.m²/rad, $K_T=38$ N.m/A, $L_m=2$ H, $R_m=21$ Ω , $B=1$ N.m/rad/sec, $n=1/20$, and $K_m=0.5$ V (rad/sec). Figure 3 illustrate the single servo control system of the robot. [13].

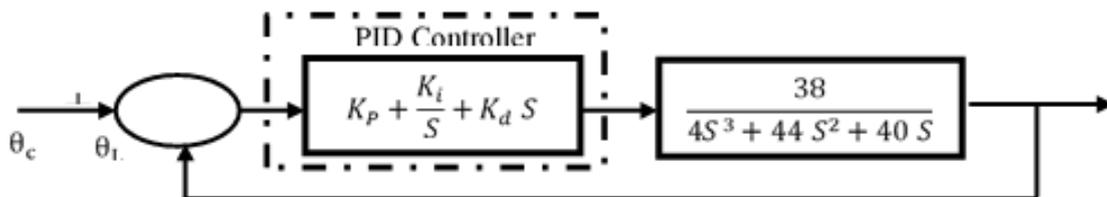


Figure 3. Robot jointed arm system

3. TUNING PID CONTROLLER BASED ON ZIEGLER -NICHOLS RULE

It is necessary to use a good tuning of the controlling parameters in order to get better performance and control with the correct parameters. In the case of using inaccurate values of the controller parameters, the performance of the system will be adequate in characteristics and also become unstable [14]. To get the closed-loop transfer function, it is done by choosing the controller setting values for K_P , K_I and K_D , and this is achieved by setting the $K_I=0$ and $K_D=0$. System stability is marginal or acceptable occur when the value of K_P is chosen so that sustainable fluctuation occurs using the Routh stability standard. This sustainable fluctuation can be obtained at the value of $K_P=11.57$, according to the study of the coefficients of the first column of the Routh table, and therefore the decisive gain, $K_{cr}=11.57$. Based on the value of $w=3.16$ rad/sec. thus, the continuous oscillation period (P_{cr}) is $2\pi/w=2$ seconds. To discover the number of times the fluctuation (w), S is replaced by jw in the properties equation. Return to Table 1, the parameters K_P , K_I and K_D will be as follows [15, 16], $K_I=1.2 K_{cr}/P_{cr}=6.94$, $K_P=0.6$, $K_D=0.075 K_{cr} \times P_{cr}=1.73$, and $K_{cr}=6.94$

Table 1. Tuning rule by ziegler-nichols

Type of controller	K_D	K_P	K_I
PID	$0.075 K_{cr} * P_{cr}$	$0.6 K_{cr}$	$1.2 K_{cr}/P_{cr}$
PI	0	$0.45 K_{cr}$	$0.54 K_{cr}/P_{cr}$
P	0	$0.5 K_{cr}$	0

MATLAB program can be easily to obtain the close-loop unit step system response by using the PID controller. Simulating result shows that the maximum over shoot is quit high (approximate 63%). However, the controller parameter can be tuned by software to reduce this value. It should be easily approached that a fine tuning starting point can be acquired through ziegler-nichols tuning rule where it's value is approximate halve that obtained [17]. $K_P=15.26$, $K_I=6.94$ and $K_D=8.39$. The PID control unit equation of transfer function is:

$$G_C(S) = \frac{K_D S^2 + K_P S + K_I}{S}$$

Table 2 contains the gain values of the PID controller.

$$G_C(S) = \frac{8.39 S^2 + 15.26 S + 6.94}{S}$$

Table 2. PID controller gain magnitudes

	KD	KI	KP
Gain magnitudes	8.39	6.94	15.26

According to the algorithm acquired above, Figure 4 shows the step response with a conventionally tuned PID controller.

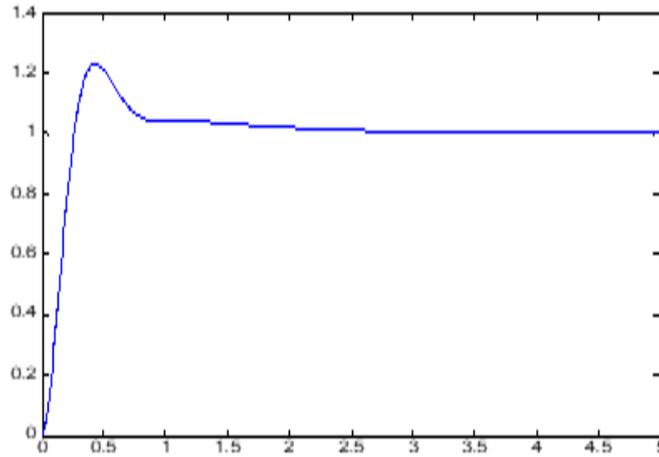


Figure 4. Step response system with PID controller unit

Depending on what was obtained from the results above. The following values can be obtained for the parameters of rising time, maximum overshooting and settling time which is 0.2 sec, 23.9% and 2sec. respectively. Among the above values, we conclude that the system has not been better tuned. Therefore, to obtain the best possible results, use the artificial bee colony optimization (ABC) technique. The technical requirements for this system are shown in Table 3 [15].

Table 3. System requirements

	Settling Time (Sec)	Max Over Shoot	Rise Time (Sec)
specification of the system	<0.9	<5 %	<0.5

4. ARTIFICIAL BEE COLONY ALGORITHM (ABC)

The artificial bee colony contains the following groups. The first group is the worker bees, second one is the watcher bees, and finally is the searcher bee. Also the colony is divided into two parts, the first colony section contains the worker artificial bees and the other section is the watcher bees. In this colony, jobs are distributed among the bees for the purpose of being carried out by specialized personal [18, 19]. These bee specialists try to greatly increase the amount of nectar stored in the hive to the optimum, and this is achieved by a good distribution of worker and self-regulation [20, 21]. The worker bees that abandoned the source of food becomes a searcher. For the source of food, each one bee is specified to the source of food, that is, the number of bees working have an equal amount of energy sources surrounding the hive. The food source position means a probable process optimization solution and the nectar origin of a food source depend on the goodness (fitness) linked with the solution [16, 17]

4.1. The algorithm of ABC

The main steps (semi-coding) to initialize the artificial BA are:

- a) Initialize the solutions of a population:

$$v_{ij} = x_{ij} + \phi_{ij} (x_{ij} - x_{kj}) \tag{9}$$

where, x_{ij} , $i=1$. FSN, (FSN is the food source number) j equal one, and D is the controller dimension problem (called K_P , K_I and K_D), where D equal three, ϕ is also a random number in the domain $[-1,1]$ and $k=1$. SN.

- b) Evaluate the population (colony size).
- c) Cycle equals one
- d) Repeat
- e) By using repeat (4), it may give to a new solutions x_{ij} for the employed bees and assess the solution.
- f) Application for processing of a greedy choice.
- g) Compute the probability values P_i , j for the solutions x_i , j by the item (3 and 4).

$$p_i = \frac{fit_i}{\sum_{n=1}^{sn} fit_n} \quad \text{--- (10)} \quad (10)$$

- h) Create new solutions x_i , j for the on looking from the selected solutions x_i , j relying on P_i , j and assess the solutions.
- i) Application for the processing of greedy choice.
- j) If the scout exist, determine abandoned solution for it, and exchange it with a novel irregular produced solution $x_{i,j}$ by select the item (4 and 5).

$$x_i^j = x_{min}^j + \phi(x_{max}^j - x_{min}^j) \quad (11)$$

where, is also a random number in the domain $[0, 1]$.

- k) Save the best achieved solution till now.
- l) Cycle becomes cycle+1.
- m) Till cycle becomes MCN (maximum cycle number).

4.2. Objective function

The new Fitness function for the parameters optimization of PID controller is known as:

$$F = W_{max} \cdot (1 - \exp(-0.5)) \cdot (M_p + E_{ss}) + W_{min} \cdot \exp(-0.5) \cdot (t_s - t_r)$$

where

M_p : is the greatest overshoot

E_{ss} : steady state error

t_r : rise time

t_s : settling time

W_{max} : max. inertia weight

W_{min} : min. inertia weight

The Parameters of ABC algorithms for optimizing the PID controller is shown in Table 4.

Table 4. Parameters of ABC algorithms

Parameter	Values
Colony size	40
No. of Iterations	100
Maximum Speed	10
(W_{max})Max. Inertia Weight	0.9
(W_{min})Min. Inertia Weight	0.3

5. ABC-PID CONTROLLER

In this work of research the ideal parameters (K_P , K_I and K_D) were determined by the application of algorithm (ABC) resulting in an impressive response rate. The ABC algorithms have been used to find the console parameters (PID) [21, 22]. The group of K_P , K_I and K_D parameters can be used to achieve good system response and reduce performance parameters in the time domain, and minimize required including stability time (T_s), elevation time (T_r), maximum overflow (% OS), and stable state error (ess). Figure 5 illustrates the robot arm design using the ABC-PID system [23-25].

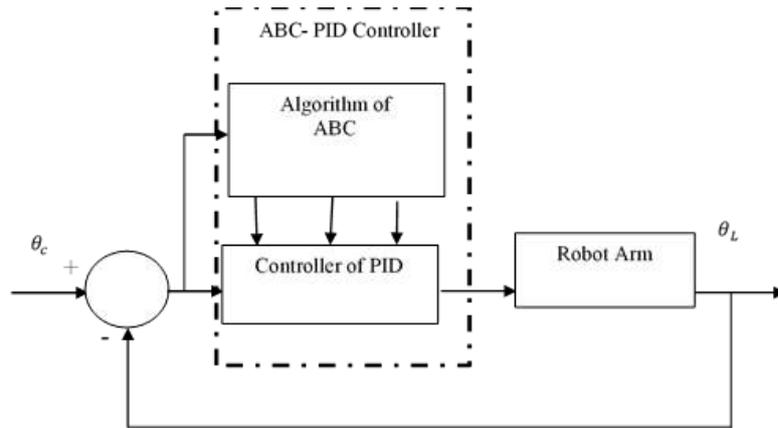


Figure 5. ABC-PID controller design for robot arm

6. RESULTS AND SIMULATION

Figures 6 and 7 illustrate the robot response to step unit by ABC-PID controller with colony size 20 and 40 respectively. Figures 8 and 9 with colony size 20 and 40 respectively illustrate the idea of how the ABC algorithm is spread to its final magnitude, and for KP, KI and KD each gain is called particle. The parameters of the two controllers ZN-PID and ABC-PID are shown in Table 5.

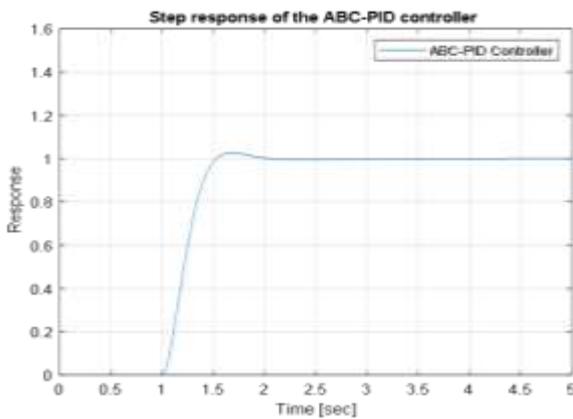


Figure 6. Robot arm step response of ABC-PID controller with colony size 20

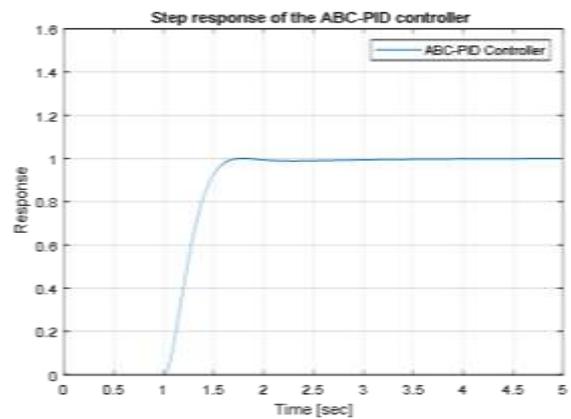


Figure 7. Robot arm step response of ABC-PID controller with colony size 40

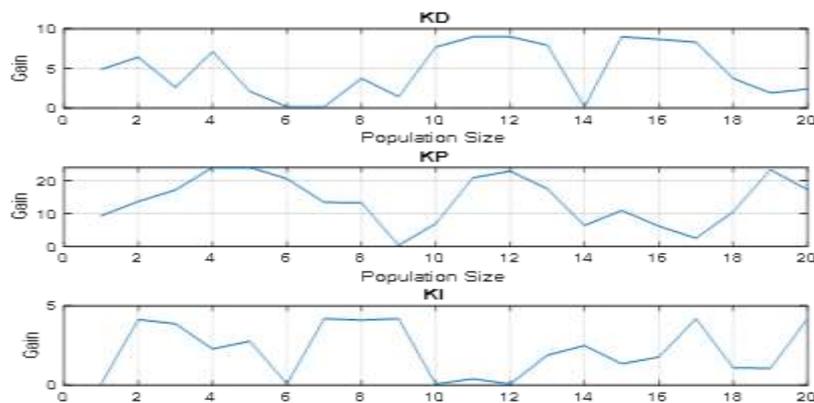


Figure 8. ABC-PID controller parameter with colony size 20

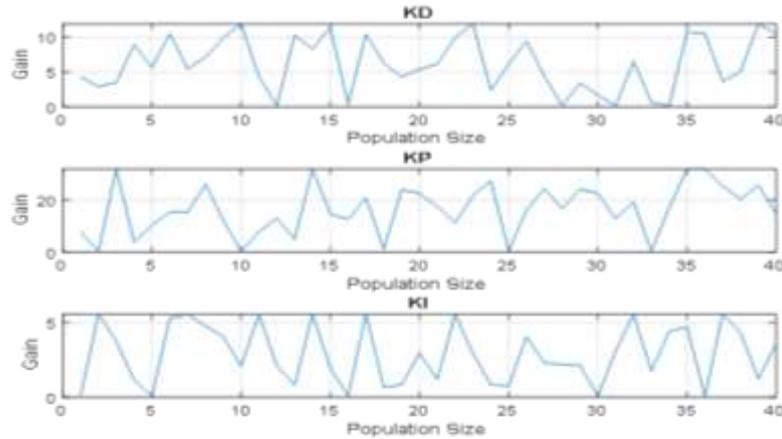


Figure 9. ABC-PID controller parameter with colony size 40

Table 5. Parameters for ZN-PID and ABC-PID controllers

Controllers Parameters	ZN-PID	ABC-PID with colony size 40	ABC-PID with colony size 20
Tr (sec)	0.2	0.387	0.332
Ts (sec)	2	0.607	0.793
Mp %	23.9	0.0563	2.63
K_D	15.26	3.8375	4.6682
K_I	6.94	0.0160	0.001
K_D	8.39	4.3535	4.8809

7. CONCLUSION

From above we can consider that the step of the responses obtained from the PID controller which was set in ABC method and within the colony size measurement 40 and 20 is better than the results compared with ziegler-nichols (and with the same colony size 40 and 20). The Ziegler-Nichols method is a good and effective way to allow the designer to evaluate the initial settings of the results from PID controller. The values of the step response results taken from the PID by designing the ABC method are better in terms of a maximum overshoot and settling time. According to the criteria for time domain performance such as settling time, rise time, overshoot, and steady-state error, the PID controller set by ABC is the better method that gives better dynamic performance compared to the way controllers set by ZN.

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BIOGRAPHIES OF AUTHORS



Ghasaan A. Sultan. He was born in Mosul in Iraq in 1962. He has got his BSc in electrical engineering in Raylovac academia in Sarajevo in Yugoslavia in 1985. He has got his MSc Electronics system in School of Electrical Engineering in University of Belgrade in 1987. He published two papers. Currently he is a lecturer in the department of medical instrumentations in the Engineering technical college of Mosul in Northern Technical University-Iraq.



Muhammed K. Jarjes. He was born in Mosul in Iraq in 1965. He has got his BSc in Electronics system engineering from Cranfield University in England in 1989. He has got his MSc Electronics from University of Mosul in 1995. He published two papers. Currently he is a lecturer in the department of medical instrumentations in the Engineering technical college of Mosul in Northern Technical University-Iraq.