International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 4 Issue 12, December - 2020, Pages: 141-147

Optimize Position Control of DC Servo Motor using PID Controller Tuning with Krill Herd algorithm

Ahmed Mohammed Alsayed, Elebaid Khalid Elsayed

Electrical Engineering Department
Sudan University of Science and Technology
Khartoum, Sudan
Email: alsaginy.ahmed@gmail.com, elebaid89.4@gmail.com

Abstract*— This paper explores the optimization of DC-server motor position control through a PID controller with a krill herd algorithm (KHA). For many reasons, such as simple structure and several other reasons, PID controllers are commonly used in industries. There are various methods available to tune the PID controller, which are used for the position control of the DC servo motor, in this paper Ziegler-Nichols (ZN), as well as KHA, are used. Compared to traditional ZN tuning methods, the results obtained by KHA showed better results than the conventional PID tuning process.*

Keywords— DC servo motor, position control, PID controller, optimization, krill herd algorithm (KHA), conventional tuning, Ziegler- Nichols method.

1. Introduction

In modern industries, electric motor servo systems are important. Servo motors are used in a number of applications, including precision and speed control [1], in industrial electronics and robotics. For control of the rate or position, or both, servo motors use a feedback controller. The PID controller has good performance as the basic continuous feedback controller. But only with adjustable tuning is properly adaptive. While several advanced control strategies have been proposed to improve system performance, including self-tuning control, adaptive model reference control, sliding mode control, and fuzzy control, traditional PI/PID controllers continue to dominate most real-time servo systems [2].

To apply the PID controller, the proportional, integral, and derivative gains must be tuned carefully. There are many methods to tune such controller like recently artificial intelligence (AI) techniques by optimization algorithms to give superior results than conventional methods tuning.

In this paper KHA is used to calculate these parameters. Krill herd optimization algorithm (KHA) has been developed as one of the modern heuristic algorithms by simulating krill herding behavior, using the Lagrangian model and its ability to solve various complex engineering problem optimization problems has been demonstrated [3]. A MATLAB analysis is performed to compare tuning using the Z-N method and the KHA method, and the results indicate the potent role of KHA in optimizing the DC servo motor position control.

2. Model of DC servo motor system:

As we have considered schematic diagram of armature-controlled DC servo motor as seen in Figure 1, DC servo motor is a linear SISO plant model with a third order transfer function.

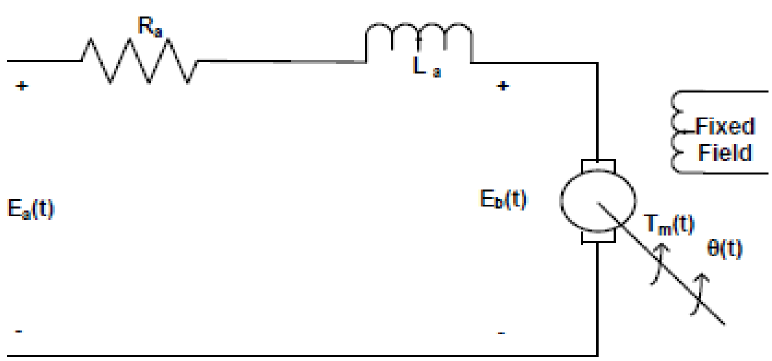

Fig. 1. DC motor servo system [4]

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 4 Issue 12, December - 2020, Pages: 141-147

The dynamic behavior of the DC servo motor can be illustrated by a block diagram as seen in Figure 2, which describes the engine's open loop transfer function.

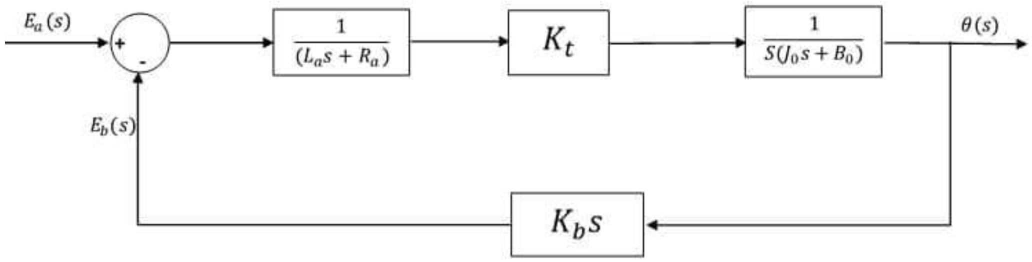

Fig. 2. Open loop position control system of DC servo motor

As shown below in the mathematical model, the mathematical relation between the angular shaft position and DC servo-motor voltage input can be determined by the physical legislation [5]:

$$G(s) = \frac{\theta(s)}{E_a(s)} = \frac{K_t}{s(L_a s + R_a)(J_0 s + B_0) + K_t K_b s} \#(1)$$

Where:
J_0 = Moment of inertia of the motor (Kgm^2 /rad)
B_0 = Viscous friction coefficient (Nm/(rad/sec))
θ = Angular displacement of the motor shaft
R_a = Armature resistance (Ω)
L_a = Armature inductance (H)
K_t = Torque constant (N-m/Ampere)
K_b = Back emf constant of motor (V/(rad/sec))
E_a = Electromotive voltage (V)

The closed loop system with unity feedback for position control of DC servo motor system is shown in Figure 3.

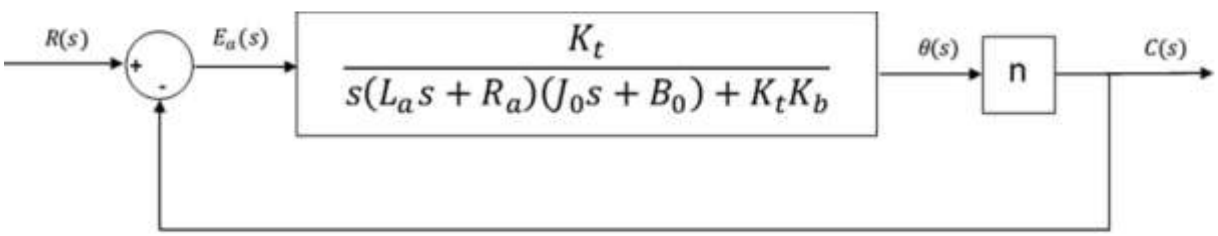

Fig. 3. *Closed loop position control system of DC servo motor*

3. PID CONTROLLER:

Thanks to its flexibility and ease of use the PID controller is commonly used in industries. A PID controller measures the "error" by setting up the control input and attempts to minimize it. By decreasing overshoots and minimizing settling time, it enhances the system's transient response and also has the potential to eradicate steady state offset by synchronized behavior. The PID controller transfer function can be written as:

$$G_{PID}(s) = K_p + \frac{K_i}{s} + K_d s \#(2)$$

The block diagram of the PID controller for the DC servo motor is shown in Figure 4.

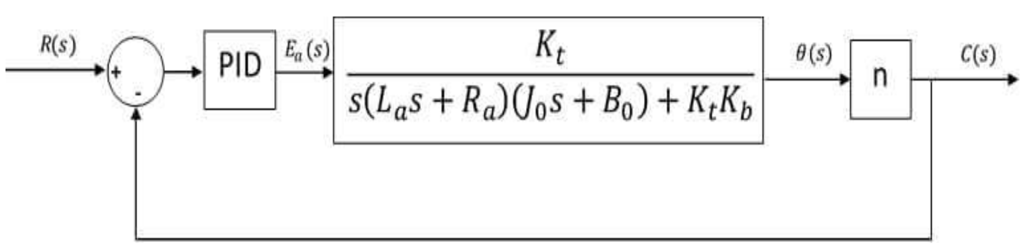

Fig. 4. PID controller for position control of DC servo motor

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 4 Issue 12, December - 2020, Pages: 141-147

4. KRILL HERD ALGORITHM (KHA)

4.1 General overview

Krill Herd (KHA) is a swarm intelligence algorithm developed to solve problems with continuous optimization to solve the global optimization function inspired by the krill individuals' herding actions. It is an effective algorithm because it includes methods of experimentation and manipulation centered on the action and movement of other individuals. As a result, Krill individuals prefer to retain high density and shift due to the influence of each other. The movement of the krill herd is defined as [3]:

$$N_i^{new} = N^{max} \times \alpha_i + \omega_n \times N_i^{old} \#(3)$$

in which N_i^{new}= current induced motion; N^{max}= maximum induced motion [6]; α_i=both of local and target effects ; ω_n = inertia weight of the induced motion[0,1]; and N_i^{old}= past induced motion. α_i is given as [3]:

$$\alpha_i = \sum_{j=1}^{NN} \hat{K}_{(i,j)} \times \hat{X}_{(i,j)} + 2\left(rand(0,1) + \frac{I}{I_{max}}\right) \times \hat{K}_{(i,best)} \times \hat{X}_{(i,best)} \#(4)$$

$$\hat{X}_{(i,j)} = \frac{X_j - X_i}{\|X_j - X_i\| + \varepsilon} \#(5)$$

$$\hat{K}_{(i,j)} = \frac{K_i - K_j}{K^{worst} - K^{best}} \#(6)$$

in which ($\hat{X}_{(i,j)}$= local impact for the individual i^{th} krill caused by the jth krill); ($\hat{K}_{(i,j)}$ = goal path result of the best krill individual) ; (K_i and K_j = fitness values of the i^{th}) and (j^{th} krill individuals, respectively; K^{best}) and (K^{worst} = best and worst fitness values for the location of the population, respectively); and (NN = number of closely individuals to the i^{th} krill); (I = current iteration); and (I_{max} = maximum iterations).

For a certain krill, the number of surrounding Krill individuals may be estimated with several special approaches [3]. For example, the number of nearest individuals may be precisely represented by a neighbor ratio. It is claimed that the actual behavior of krill individuals indicates the distance from sensing (d_s) is an adequate attribute for assessing individuals of the surrounding krill as seen in the Figure. 5.

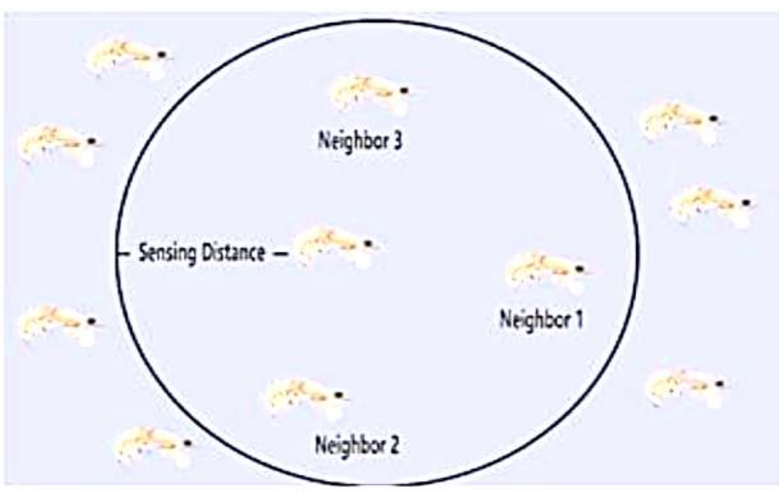

Fig. 5. *An individual's herd sensing [7]*

In each step, the distance of sense is given by: [3]:

$$d_{(s,i)} = \frac{1}{5N}\sum_{j=1}^{N}\|X_i - X_j\| \#(7)$$

in which N = individuals' numbers.

4.2 Foraging motion and physical diffusion

Foraging motion is estimated by two elements of food location and previous experience of its location as follows [3]:

$$F_i = 0.02\left(2\left(1-\frac{I}{I_{max}}\right)\times \hat{K}_{(i,food)}\times \hat{X}_{(i,food)} + \hat{K}_{(i,best)}\times \hat{X}_{(i,best)}\right) + \omega_f \times F_i^{old} \#(8)$$

$$X^{food} = \frac{\sum_{i=1}^{N}\frac{1}{K_i}\times X_i}{\sum_{i=1}^{N}\frac{1}{K_i}} \#(9)$$

in which (F_i= current forging motion); (ω_f= Inertia weight of the motion for foraging;) (X^{food} = Estimated nutritional position;) ($K_{(i,best)}$ = the best location of the i^{th} krill individual previously identified) [3].

KHA integrates the random method of disseminating Krill individuals to maximize the diversity of the populations. At the stage of optimization, this approach preserves or increases the variety of organizations. The degree to which krill individuals are separated can be described as follows:

$$D_i = D^{max}\times\left(1-\frac{I}{I_{max}}\right)\times \delta \#(10)$$

in which (D^{max}= Maximum rate of diffusion) [3]; (δ = directional vector that is random and its arrays consist of random numbers in the range [-1,1]).

4.3 Motion process in KHA

The location vector of the i^{th} krill individual in the time interval from t to t + Δt is determined by [3]:

$$X_i(t+\Delta t) = X_i(t) + \Delta t \times \frac{dX_i}{dt} \#(11)$$

Note that Δt is an important parameter that should be tuned carefully, and it can be estimated by [3]:

$$\Delta t = C_t \times \sum_{j=1}^{NV}\left(UB_j - LB_j\right) \#(12)$$

in which (NV = variables' number) ; and (UB_j and LB_j= lower and upper limits), respectively. (C_t is a constant number in the range (0,2)).

5. Objective Function

In the literature there are different indices as cost functions for optimization problems such as integral of absolute error (IAE), integral of squared error (ISE) and many others [8].

In this work a time domain cost function proposed by Gaing that contains response characteristics is used as given by: [8]

$$\text{Min of } J(K_p, K_i, K_d) = \left(1-e^{-\beta}\right)\left(M_p + E_{ss}\right) + e^{-\beta}(t_s - t_r) \#(13)$$

Here, E_{ss}, M_p, t_r, And t_s Represent A Steady-State Error, Overshoot, Rise Time, And Settling Time Respectively. β Is A Weighting Factor Within A Range Of [0.5,1.5], Which Is Set As 1.0 In This Work.

6. Objective Function

To implement the position control of the DC servo motor system, the following parameter values are used as given by table 1[9]:

Table 1: Parameter values for DC servo motor system

Parameter	Value
R_a	1.0 Ω
L_a	0.5 H
K_t	0.01 N-m/Ampere
K_b	0.01 V/(rad/sec)
J_0	0.01 Kg-m^2 /rad
B_0	0.1 N-m/(rad/sec)

International Journal of Engineering and Information Systems (IJEAIS)
ISSN: 2643-640X
Vol. 4 Issue 12, December - 2020, Pages: 141-147

After substitute values from table 1, the open loop transfer function is:

$$G(s) = \frac{\theta(s)}{E_a(s)} = \frac{0.01}{0.005\ s^3 + 0.06\ s^2 + 0.1001\ s} \#(14)$$

The closed loop position system with a unity feedback is given by:

$$G_o(s) = \frac{C(s)}{R(s)} = \frac{0.01}{0.005\ s^3 + 0.06\ s^2 + 0.1001\ s + 0.01} \#(15)$$

The system is tuned firstly using Z-N method, then it is tuned by KHA, and the PID gains for the two cases are given in table 2.

Table 2: PID parameters for Z-N and KHA

Method	K_p	K_i	K_d
Z-N	70.6588	100.6349	12.4029
KHA	41.6490	1.2394	26.1789

Unit step responses for the original system, system tuned using Z-N, and the system tuned using KHA are shown in Figure 6.

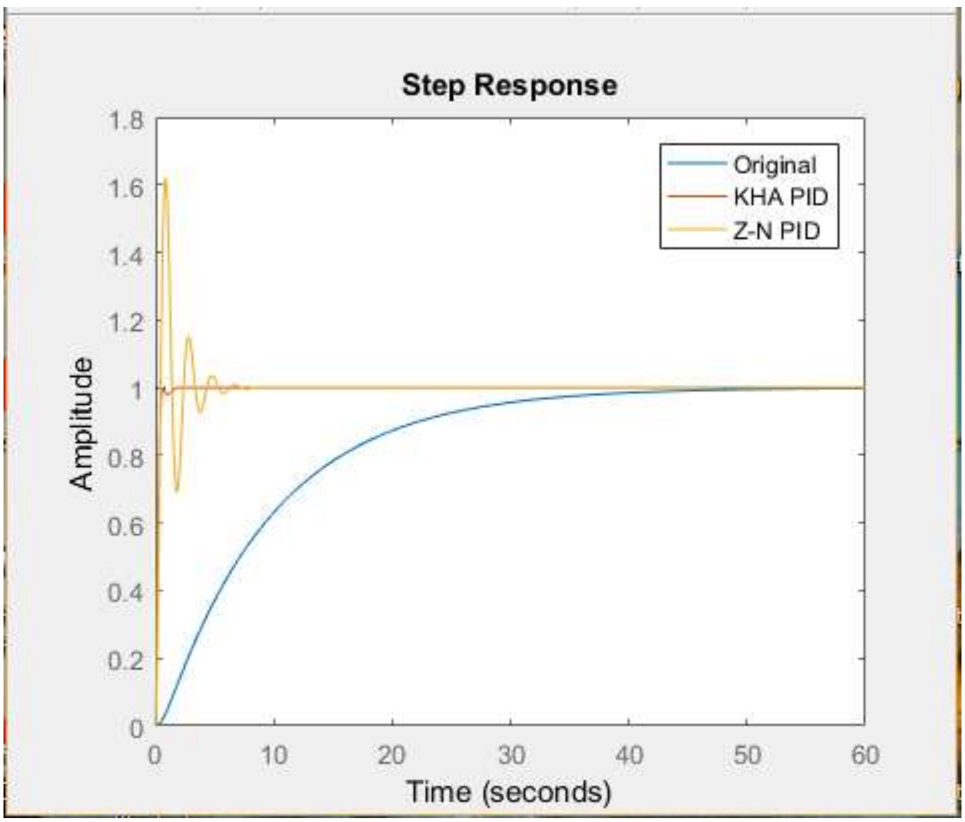

Fig. 6. *Step responses for the three cases*

Characteristics for the step responses are shown in table 3.

Table 3: Time domain specifications

Case	M_p(%)	t_r(sec)	t_s(sec)	E_{ss}(%)
Original system	0	20.6	37.3	0
Z-N PID	62	0.292	5.08	0
KHA PID	0	0.320	0.497	0

From the step responses and time domain specifications shows in table above, we find that the position control for the DC servo motor system is optimized by using KHA rather than ZN which cause the system to have an overshoot. Table 3 shows clearly the powerful effect of KHA which is clearly observed by seeing the great improvements in time domain specifications as compared to original system, also it is clear that this algorithm achieves superior results than ZN method.

7. Conclusion

PID tuning for the position control of the servomotor is seen in this paper using the KHA optimization method. The tuning of PID controllers is achieved by decreasing the time domain objective function suggested by Gaing. MATLAB is used to conduct experimental results as well as different performance indices and from the results it is clear that the position control for the DC servo motor system can be optimized to a better performance by using KHA rather than conventional methods.

8. References

[1] O. Wahyunggoro and P. D. Student (2008), "Evaluations of Fuzzy-Logic-Based Self Tuning PI Controller and Fuzzy-Scheduled PID Controller for DC Servomotor Nordin Saad Simulation of DC Servomotor Control,".

[2] G. Li and K. M. Tsang (2007), "Concurrent Relay-PID Control for Motor Position Servo Systems," vol. 5, no. 3, pp. 234–242,.

[3] A. Hossein and A. Hossein (2012), "Commun Nonlinear Sci Numer Simulat Krill herd : A new bio-inspired optimization algorithm," *Commun. Nonlinear Sci. Numer. Simul.*, vol. 17, no. 12, pp. 4831–4845, doi: 10.1016/j.cnsns.2012.05.010.

[4] R. Bindu and M. K. Namboothiripad (2012), "Tuning of PID Controller for DC Servo Motor using Genetic Algorithm," vol. 2, no. 3.

[5] N. S. Rathore and V. P. Singh (2015), "Tuning of PID Controller for Position Control of DC Servo Motor using Luus-Jaakola Optimization,".

[6] E. E. Hofmann, A. G. E. Haskell, J. M. Klinck, and C. M. Lascara,(2004) "Lagrangian modelling studies of Antarctic krill (Euphausia superba) swarm formation," vol. 631, 2004, doi: 10.1016/j.icesjms.2004.03.028.

[7] A. La, M. A. Al-betar, M. A. Awadallah, A. T. Khader, and L. M. Abualigah, "Ac ce p te d cr t," *Appl. Soft Comput. J.*, 2016, doi: 10.1016/j.asoc.2016.08.041.

[8] D. K. Sambariya,(2017) "Optimal Design of PID Controller For An AVR System Using Monarch Butterfly Optimization,".

Authors

Ahmed Mohammed Alsayed, Received the B.Eng in Electrical engineer from Sudan University of Science and Technology, interested on control engineering especially optimal, nonlinear and robust as well as the new trend of fractional order control. Also, He interested in Artificial Intelligence especially machine learning and deep learning and currently he worked as a junior machine learning engineer as well as an instructor for machine learning and natural language processing (NLP) workshops.

Elebaid Khalid Elsayed, Received the B.Eng in Electrical engineer from Sudan University of Science and Technology, he interested on control engineering especially nonlinear and robust with applied in drone vision. Also, He interested in Artificial Intelligence especially machine learning and deep learning and currently, applied computer vision for drone and developed algorithm for this application.