Determination of the PID Controller Parameters for Speed and Position Control of DC Motor using Gravitational Search Algorithm

Serhat DUMAN[1], Dinçer MADEN[2], Uğur GÜVENÇ[3]

[1]Department of Electrical Education, Technical Education Faculty, Duzce University, Duzce, 81620, TURKEY
serhatduman@duzce.edu.tr
[2]Department of Electrical and Electronics Engineering, Engineering Faculty, Duzce University, Duzce, 81620, TURKEY
dincermaden@duzce.edu.tr
[3]Department of Electrical and Electronics Engineering, Faculty of Technology, Duzce University, Duzce, 81620, TURKEY
ugurguvenc@duzce.edu.tr

Abstract

In this paper we use a new search heuristic called Gravitational Search Algorithm (GSA) to determination of the optimal PID controller parameters in the speed and position control of a DC motor. The model of a DC motor is considered as second and third order system. Mean squared error (MSE) performance index has been used as objective function. End of the optimization process, the rise and the settling times and the overshoot are compared to those reported in the literature. To show that effectiveness of proposed method are compared with Ziegler-Nichols method in speed control of DC motor. Simulation results show the effectiveness and robustness of proposed controllers to provide the speed and position control of DC motor.

1. Introduction

At the present time, DC motors have been widely used in many industrial applications due to high performance of speed control and position control. In this applications speed and position are generally controlled by proportion-integration (PI), proportion-derivation (PD), and proportion-integration-derivation (PID) controller. PID controller is simple, robust and more preferable compare to PI or PID because of many advantages [1]. Although the simple structure and robustness of PID control method, optimally tuning coefficient of proportion, integration and derivation have been quite difficult via conventional methods such as Ziegler-Nichols, Karl-Astrom etc.[2].

Nowadays, many heuristic methods have been used for tuning of PID controller parameters. Thomas and Poongodi proposed to determination of the PID controller parameters in position control of DC motor using the genetic algorithm [3]. Nagaraj et al. used soft computing techniques for tuning of PID controller parameters [4]. Al-Hamouz and Al-Duwaish utilized genetic algorithm for a new variable structure DC motor controller [5]. Xia et al. investigated speed control of brushless DC motor using genetic algorithm based fuzzy controller [6]. Gargari and Lucas designed optimal PID controller using imperialist competitive algorithm [7]. Moghaddas et al. utilized particle swarm optimization algorithm for determination PID controller parameters in speed control of DC motor [8]. Nasri et al. proposed particle swarm optimization algorithm for optimum design PID controller in speed control of linear brushless DC motor [9]. Allaoua et al. utilized particle swarm optimization algorithm for neuro-fuzzy DC motor speed control [10].

One of the recently developed stochastic algorithms is the gravitational search algorithm (GSA) based on the Newton's law of gravity and mass interactions [11]. GSA has been verified high quality performance in solving different optimization problems in the literature [12-18]. In this paper, a newly developed heuristic optimization called GSA method is proposed to determinate of PID controller parameters for speed and position control of DC motor. This paper has been organized as follows: in section 2 the DC motor is described and the model of it is shown. Gravitational search algorithm describes in section 3. Section 4, describes how GSA is used to design the PID controller values optimally for a DC motor speed control and position control. A comparison between the results obtained by the proposed approach and ref. [4] via simulation the DC motor position control and speed control are offered in section 5. The paper is concluded in section 6.

2. Modeling the System

In this study, proposed approach has been simulated a DC shunt motor as is shown in Fig. 1. DC shunt motors have the field coil in parallel with the armature. The current in the field coil and the armature are independent of one another. Consequently, these motors have perfect speed and position control. The characteristics equations of the DC motor can be defined by the following equations [1,3];

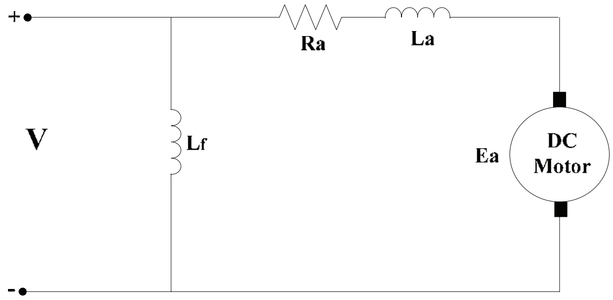

Fig. 1. Diagram of the DC shunt motor

$$V = R_a i + L_a \frac{di}{dt} + e_a \tag{1}$$

$$T_e = k_m i \tag{2}$$

$$T_e = J\frac{d\omega}{dt} + B\omega \tag{3}$$

$$T_e = J\frac{d^2\theta}{dt^2} + B\frac{d\theta}{dt} \tag{4}$$

$$e_a = k_e\omega = k_e\frac{d\theta}{dt} \tag{5}$$

The transfer functions are defined for speed and position control of DC motor, respectively.

$$\frac{\omega(s)}{V(s)} = \frac{K_e}{JL_a s^2 + (R_a J + BL_a)s + (K_e^2 + R_a B)} \tag{6}$$

$$\frac{\theta(s)}{V(s)} = \frac{K_e}{JL_a s^3 + (R_a J + BL_a)s^2 + (K_e^2 + R_a B)s} \tag{7}$$

Where, *Ra* is armature resistance, *La* is armature inductance, *i* is armature current, *V* is armature voltage, e_a is back emf voltage, *Ke* is back emf constant, *Km* is torque constant, Tm is torque developed by the motor, ω is angular speed of shaft, θ is angular displacement of shaft, *J* is moment of inertia of motor and load, *B* is frictional constant of motor and load.

3. Gravitational Search Algorithm

Rashedi et al. proposed a new meta-heuristic searching algorithm called Gravitational Search Algorithm (GSA) in 2009. The Gravitational Search Algorithm is a swarm-based and also is memory-less optimization algorithm based on the Newton's laws of gravity and mass interaction. The gravitational force between two particles is directly proportional to the product of their masses and inversely proportional to the square of the distance between them. According to the proposed algorithm, agents are assumed to be objects that their performances are measured by means of masses. The whole agents pull each other by the gravitational attraction force and this force induces the movement of all agents globally towards the agents with heavier masses. In GSA, each mass has four particulars: its position, its inertial mass, its active gravitational mass and passive gravitational mass. The position of the mass equaled to a solution of the problem and its gravitational and inertial masses are specified using a fitness function [11]. GSA algorithm can be summarized following steps:

3.1. Step 1: Initialization

When it is assumed that there is a system with N (dimension of the search space) masses, position of the i^{th} mass is described as follows. At first, the positions of masses are fixed randomly.

$$X_i = (x_i^1, \ldots, x_i^d, \ldots x_i^n) \quad \text{for, } i=1,2,\ldots,N \tag{8}$$

where, x_i^d is the position of the i^{th} mass in d^{th} dimension.

3.2. Step 2: Fitness Evaluation of All Agents

In this step, to execute for all agents at each iteration and *best* and *worst* fitness are computed at each iteration described as follows.

$$best(t) = \min_{j\in\{1,..,N\}} fit_j(t) \tag{9}$$

$$worst(t) = \max_{j\in\{1,..,N\}} fit_j(t) \tag{10}$$

where $fit_j(t)$ is the fitness of the j^{th} agent of iteration *t* , *best(t)* and *worst(t)* are best (minimum) and worst (maximum) fitness of all agents.

3.3. Step 3: Compute the Gravitational Constant (G(t))

In this step, the gravitational constant at iteration *t* (*G(t)*) is computed as follows.

$$G(t) = G_0 \exp(-\alpha \frac{t}{T}) \tag{11}$$

where G_0 is the initial value of the gravitational constant chosen randomly, α is a constant, *t* is the current iteration and *T* is the total iteration number.

3.4. Step 4: Update the Gravitational and Inertial Masses

In this step, the gravitational and inertial masses are updated for each agent at iteration as follows.

$$M_{ai} = M_{pi} = M_{ii} = M_i, \qquad i = 1,2,\ldots,N \tag{12}$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \tag{13}$$

where $fit_i(t)$ is the fitness of the i^{th} agent at iteration *t*.

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_j(t)} \tag{14}$$

where M_{ai} is the active gravitational mass of the i^{th} agent, M_{pi} is the passive gravitational mass of the i^{th} agent, M_{ii} is the inertia mass of the i^{th} agent, *Mi(t)* is the mass of the i^{th} agent at iteration *t*.

3.5. Step 5: Calculate the Total Force

In this step, the total force acting on the i^{th} agent ($F_i^d(t)$) is calculated as follows.

$$F_i^d(t) = \sum_{j\in kbest j\neq i} rand_j F_{ij}^d(t) \tag{15}$$

where $rand_j$ is a random number between interval [0,1] and *kbest* is the set of first K agents with the best fitness value and biggest mass.

The force acting on the i^{th} mass ($M_i(t)$) from the j^{th} mass ($M_j(t)$) at the specific iteration t is described according to the gravitational theory as follows.

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t)\times M_{aj}(t)}{R_{ij}(t)+\varepsilon}(x_j^d(t)-x_i^d(t)) \quad (16)$$

where $R_{ij}(t)$ is the Euclidian distance between i^{th} and j^{th} agents $\left(\left\|X_i(t),X_j(t)\right\|_2\right)$ and ε is the small constant.

3.6. Step 6: Calculate the Acceleration and Velocity

In this step, the acceleration $(a_i^d(t))$ and velocity $(v_i^d(t))$ of the i^{th} agent at iteration t in d^{th} dimension are calculated through law of gravity and law of motion as follows.

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \quad (17)$$

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t) \quad (18)$$

where $rand_i$ is the random number between interval [0,1].

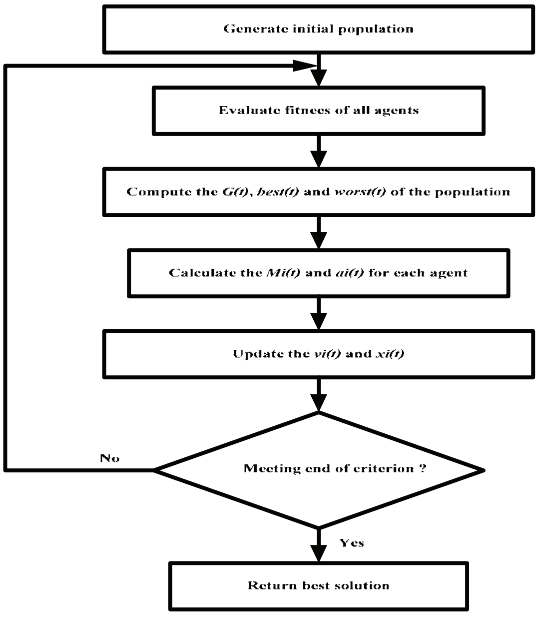

Fig. 2. The principle diagram of the GSA [11]

3.7. Step 7: Update the Position of Agents

In this step the next position of the i^{th} agents in d^{th} $(x_i^d(t+1))$ dimension are updated as follows.

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \quad (19)$$

3.8. Step 8: Repeat

In this step, steps from 2 to 7 are repeated until the iterations reach the criteria. In the final iteration, the algorithm returns the value of positions of the corresponding agent at specified dimensions. This value is the global solution of the optimization problem also.

All these steps explained above describes how the GSA works. Besides, the principle diagram of the GSA is illustrated in Fig. 2.

4. Tuning of PID Parameters based Gravitational Search Algorithm

In the proposed approach, the PID control structure is shown in Fig. 3. The PID parameters K_p, K_i, and K_d are tuned using the GSA technique discussed in this section.

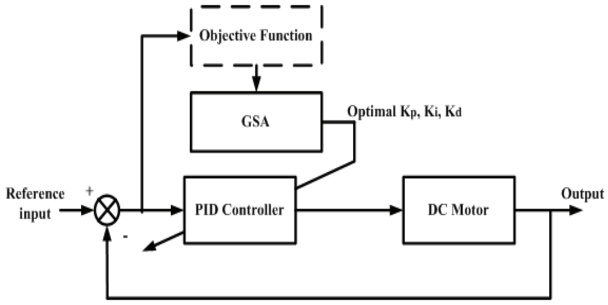

Fig. 3. The block diagram of proposed PID controller with GSA algorithm

The variable $e(t)$ presents the tracking error which is difference between the reference input value and real output. This error signal will be sent to the PID controller and the controller computes both the derivate and the integral of this error signal [2]. In this study, Mean Squared Error (MSE) is considered as objective function for optimization of PID controller parameters. MSE objective function is defined as follows:

$$MSE = \left(\frac{\sum_{i=1}^{N}(y-\hat{y}(i))^2}{N}\right) \quad (20)$$

$$J = \frac{1}{1+MSE} \quad (21)$$

Where J is the objective function (MSE).

5. Results of Simulation

Proposed method has been applied to tune of optimal PID controller parameters. In order to verify the performance of proposed GSA approach based on Newtonian physical law of gravity and law of motion which is tested for speed and position control of DC motor.

The setting parameters of proposed approach are given in Table 1.

Table 1. Setting parameters of proposed approach for optimal PID controller

Parameters			
N	**G_0**	**α**	**T**
100	100	7	200

The parameters of the electric DC motor have the following value respectively, J=0.042 Kgm^2/rad, B=0.01625 Nm/(rad/sec), Km=0.9 Nm/A, Ke=0.9 V/(rad/sec), L=0.025 Henry, R=5 ohm. These nominal values are taken from ref. [4]. Firstly, position control of DC motor has been simulated to evaluate the effectiveness of the proposed optimal PID controller based on GSA. According to optimal PID controller parameters obtained from proposed GSA in position control of DC motor, peak overshoot, settling time and rise time are compared with ref. [4] and exhibited in Table 2. The position response of PID controller tuning parameters using gravitational search algorithm strategy is shown in Fig 4. Root locus analysis allows the exploration of time domain and stabilization behaviors of the position control of DC motor. The root locus curves are shown in Fig. 5. The closed loop poles of the position control of DC motor are represented in Table 3.

Table 2. Comparison of the simulation results

Methods	Peak overshoot (%)	Settling Time (sec)	Rise time (sec)
ZNST [4]	41.4	2.56	0.242
Continuous Cycling [4]	87.6	4.31	0.0474
PSO [4]	8.81	0.205	0.014
EP [4]	13	0.324	0.0317
GA [4]	12.9	1.15	0.0385
GSA	**6.7**	**0.0396**	**0.0131**

Table 3. Poles of closed loop for position control

Closed Loop Poles
-98.16+114.90i
-98.16-114.90i
-2.20
-1.87

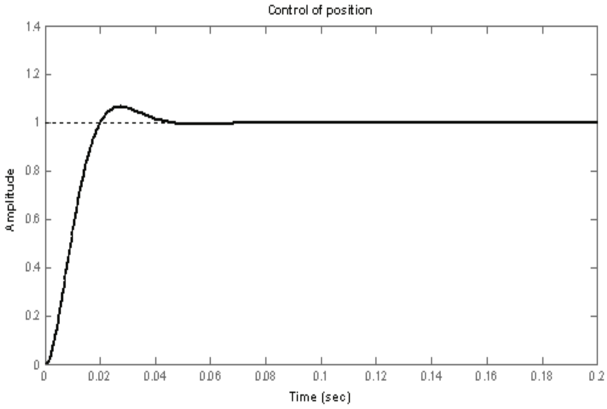

Fig. 4. The position response of optimal PID controller tuning parameters

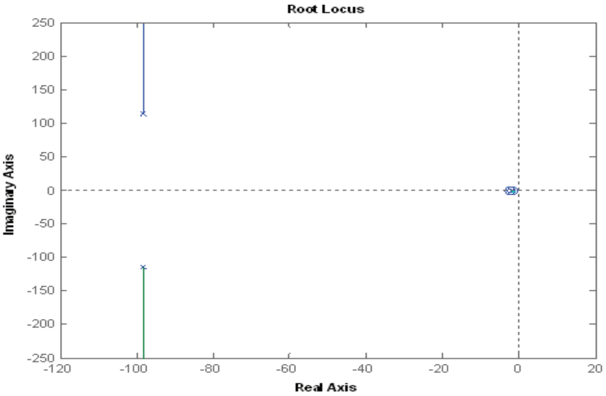

Fig. 5. Root locus curve of the position control

Secondly, speed control of DC motor has been simulated to evaluate the effectiveness of the proposed optimal PID controller based on GSA and results obtained from proposed approach are compared with Ziegler-Nichols method. Optimal PID controller parameters obtained from proposed GSA in speed control of DC motor, peak overshoot, settling time and rise time are compared with Ziegler-Nichols and shown in Table 4. The speed response of PID controller tuning parameters using gravitational search algorithm strategy and Ziegler-Nichols is shown in Fig. 6 and Fig. 7. Root locus analysis allows the exploration of time domain and stabilization behaviors of the speed control of DC motor. The root locus curves are shown in Fig. 8. The closed loop poles of the speed control of DC motor are represented in Table 5.

Table 4. Comparison of the simulation results

Methods	Peak overshoot (%)	Settling Time (sec)	Rise time (sec)
ZN	44.2	0.0649	0.00538
GSA	**0.0002**	**0.00000458**	**0.00000257**

Table 5. Poles of closed loop for speed control

Closed Loop Poles
-837910
-0+0i
-0+0i

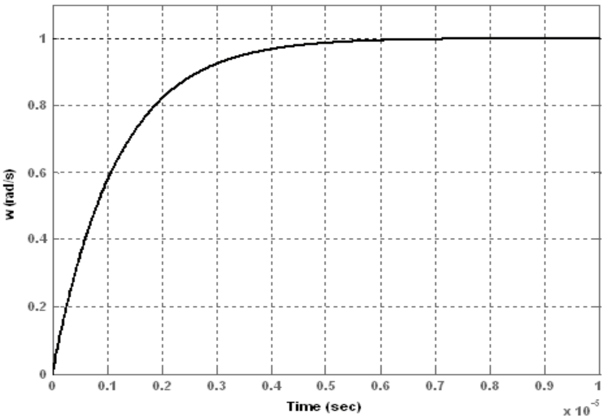

Fig. 6. The speed response of optimal PID controller tuning parameters using GSA

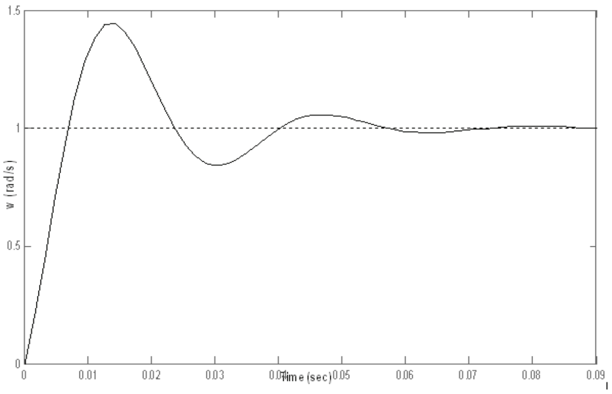

Fig. 7. The speed response of PID controller tuning parameters using Ziegler-Nichols method

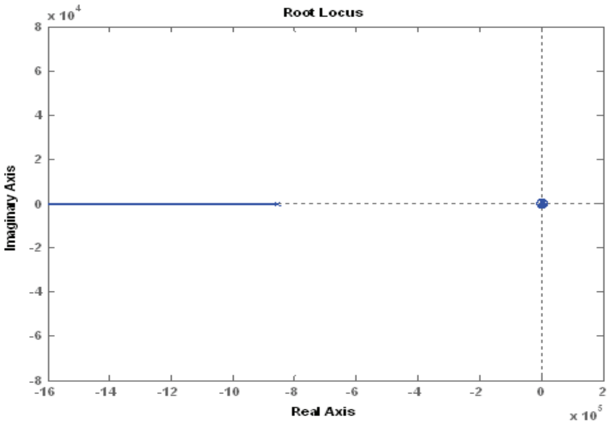

Fig. 8. Root locus curve of the speed control

6. Conclusion

In this paper, a novel heuristic approach GSA for tuning PID controller parameters has been presented and applied to speed and position control of DC motor. The PID controller is designed in such a way that it minimizes the sum of settling time, rise time, maximum overshoot and mean squared error. Results obtained through simulation of DC motor show that PID controller is designed with proposed approach can be improved the dynamic performance of the system. Results obtained are compared to other reported in the literature for position control and compared with Ziegler-Nichols for speed control of DC motor. The designed PID controller with GSA is much better which presented satisfactory performances and own good robustness in terms of the rise time, settling time and maximum overshoot.

7. References

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