OPTIMAL PID CONTROLLER OF POSITION TRACKING DC SERVOMOTOR CONTROL BASED PARTICLE SWARM OPTIMIZATION

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ABSTRACT
In this work, a Particle Swarm optimization (PSO) algorithm is proposed to obtain optimal PID controller parameters of a DC servomotor drive. This work has a very important issue due to a wide range employed in various servomechanisms. The proposed approach has superior feature, flexible execution, stable convergence characteristic, and high-quality solution efficiency. The simulation results using MATLAB 2014a environment show that the proposed objective function provides more proficient in improving dynamic response, better convergence, and fast response than the other methods based on maximum overshoot, rise time, and settling time of system step response.

Keywords: DC servomotor, PID controller, PSO, Position Tracking, Transient response

التوليف الامثل لمسيطر PID في التحكم بتتبع الموقع لمحرك التيار المستمر باستخدام خوارزمية الحركة المثلى لاسراب الجسيمات

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قدم هذا العمل خوارزمية الحركة المثلى لاسراب الجسيمات للحصول على القيم المثلى لمعاملات المسيطر PID للسيطرة على محرك تيار مستمر. ان اهمية هذا العمل جاءت نتيجة للاستخدام الواسع لمحركات التيار المستمر في نظم التحكم. ان المنهج المقترح سهل التنفيذ و ذو دقة عالية و ان نتائج المحاكاة باستخدام بيئة MATLAB 2014a تبين ان دالة الهدف المقترحة توفر كفاءة عالية في تحسين الاستجابة الديناميكية و الاستجابة السريعة مقارنتا مع النظريات الاخرى على اساس الحد الاقصى للتجاوز و زمن الارتفاع و زمن الاستقرار لاستجابة النظام0

الكلمات المفتاحية: محرك تيار مستمر, المسيطر PID, خوارزمية الحركة المثلى لاسراب الجسيمات, تتبع الموقع, الاستجابة العابرة

INTRODUCTION

Now a day, DC servomotors have been widely used as an actuator for direct-drive and motion control applications, like as automation process, robot manipulators, mechanical motion and others. Servomotor is indispensable in industrial application because of its high reliability, flexibility, and low cost. It has a rotary actuator that can provide a precise control for angular position. A feedback control of servomotor is used to control the speed or position or both. A PID controller is widely used in speed and position control systems due to simple structure and implementation [1]. The PID gains (K_P, K_I, and K_D) should be tuned accurately. However, many methods have been developed to tune these gains. A different approach have been reported in the literature to tune PID gains using soft computational intelligence methods like Neural Network, Fuzzy system, Genetic algorithm, and Particle swarm optimization [2]. In [3] the authors present a Genetic Algorithm GA to tune PID parameters of DC servomotor position control, it was implemented in MATLAB environment. A comparison with classical method (Ziegler-Nichols) was made to emphasize of GA-PID controller improvement. In [4] the authors present a new approach to obtain optimal PID parameters, Genetic Algorithm was used to verify this issue using new objective function for DC servomotor. In [5] the authors proposed a Sliding Mode controlled (SMC) method for DC servo motor, it was carried out through MATLAB / SIMULINK environment.

This paper proposed a Particle Swarm algorithm to tune PID gains. Firstly different performance indices are implemented. This includes IAE, ISE, and ITAE which IAE was experimentally better than the other. Secondly new objective function is achieved best performance in the controlled DC servomotor system comparison with different common performance criteria to ensure the robustness of the proposed controller.

MATHEMATICAL MODEL OF DC SERVOMOTOR

Figure (1) shows that equivalent circuit of armature control of DC servomotor. Using Kirchhoff voltage law in armature circuit [6]:

$$e_a = R_a i_a + L_a \frac{di_a}{dt} + e_b \qquad (1)$$

The back emf of motor

$$e_b = k_b \dot{\theta}_m \qquad (2)$$

The air-gap flux is given by

$$\emptyset = K_f i_f \qquad (3)$$

The develop torque is proportional to product of $\emptyset$ and armature current I_a.

$$T = k_t \emptyset i_a \qquad (4)$$

Or by substituting equation (3) in (4)

$$T = k_t K_f i_f i_a \qquad (5)$$

Since the field is constant

$$T = k_T I_a \tag{6}$$

The developed torque is used to drive the system having a total inertia J and to overcome the damping B and twisting the coupling shaft to the load.

$$T = J\ddot{\theta}_m + B\dot{\theta}_m \tag{7}$$

Where:
T: developed torque Nm
$\emptyset$: Flux Weber.
k_t: torque constant Nm/A.
I_a: Armature current A.
θ_m: Angular position of the motor shaft in radians.
J: Rotor inertia kgm^2/rad.
B: Viscose friction coefficient Nm/(rad/sec).
e_b: Back emf V.
k_b: Back emf constant V/(rad/sec).
e_a: Armature voltage V.
R_a: Armature resistance Ω.
L_a: Armature inductance H.

Take Laplace transform

$$I_a(s) = \frac{E_a(s)-E_b(s)}{(R_a+SL_a)} = \frac{E(s)}{(R_a+SL_a)} \tag{8}$$

$$E_b(s) = K_b S\theta_m(s) \tag{9}$$

$$T(s) = K_T I_a(s) \tag{10}$$

$$T(s) = JS^2\,\theta_m(s) + BS\theta_m(s) \tag{11}$$

The transfer function between shaft position and armature voltage is:

$$\frac{\theta(s)}{E(s)} = \frac{K_T}{JL_aS^3+(R_aJ+L_aB)S^2+(R_aB+K_bK_T)\,S} \tag{12}$$

AN OVERVIEW OF PARTICLE SWARM OPTIMIZATION (PSO) ALGORITHM

American electrical engineer Eberhart and psychologist Kennedy developed a PSO algorithm depend on the similarity of swarm of bird and fish pool [7]. In PSO the system is initialized the swarm assigning random position and searches for optimal location by update of generations. Each particle is flying out of the problem search space by following the current optimum particles. The velocity of each particle can be modified as follows:

$$V_i^{k+1} = WV_i^k + C_1R_1 * \left(Pbest - S_i^k\right) + C_2R_2 * \left(gbest - S_i^k\right) \tag{13}$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \tag{14}$$

Where:
V_i^k: Velocity of particle I of iteration k.
W: inertia weighting factor.
R_1, R_2: Random number between 0 and 1.
C_1, C_2: Acceleration constant.
S_i^k: Current searching point.
S_i^{k+1}: modified searching point.
$Pbest$: Best position of the i^{th} particle.
$gbest$: The index of best particle among the entire particle in the population.

During iteration, the particles have been update velocity and position till reach optimum or maximum iteration.

DESIGN OF PID BASED ON PSO CONTROLLER

PSO can be utilized to tune the gains of PID controller to enclose optimal performance of the system. In **Figure (2)** the schematic diagram consist of a PID controller with auto-tuning of its gains based PSO and a controlled plant. A set of gains can get a better response, which will outcome from performance index. The most common performance indices are summarized in **Table (1)**, a minimization objective function is selected as follows:

$$Objective\ Function = \frac{1}{J} \qquad (15)$$

These performance indices have an advantage and disadvantage. The disadvantage of the IAE (Integral of Absolute Error) and ISE (Integral of Squared Error) criteria is short overshoot but long settling time. ITAE (Integral of Time Multiplied Absolute Error) criteria can overcome this disadvantage but it is complex and requires time to its analytical formula [8]. In [8] the following performance criterion is defined:

$$W(k) = \left(1 - e^{-\beta}\right)\left(M_p + e_{ss}\right) + e^{-\beta}\left(t_s - t_r\right) \qquad (16)$$

Where:
$W(k)$: Performance function.
K: [K_p, K_i, K_d].
β: weighting factor
M_p: Maximum overshoot.
e_{ss}: Steady stat error.
t_s: Settling time.
t_r: Rise time.

The weighting factor β is used to calibrate of the performance criteria to get the best response. For β large than 0.7, steady-state error and the maximum overshoot will be decreased, while when β less than 0.7, the rise and settling time will be decreased [8]. In this work, we set β to 0.5 according to the trials, which can get optimum step response for position tracking system of DC servomotor.
To overcome all the defects mentioned earlier, the objective function is modified in this work as follows:

$$Objective\ Function = \frac{1}{W(k)*J} \quad (17)$$

Equation (17) can be enhancing the performance of PSO-PID algorithm and increase the efficiency and accuracy. **Figure (3)** illustrates the PSO-PID algorithm flowchart.

SIMULATION RESULTS

The proposed PSO-PID algorithm is utilized to the DC servomotor drive. The DC servomotor parameters are given in appendix A.

The particle swarm optimization algorithm parameters are:

- population size: 50
- Maximum iteration: 100.
- Inertia weighting factor W: 0.9.
- Acceleration factors C_1=2, and C_2=1.4.

The bounds of each particle are set to lie between 0 to +100. Each particle set of the PID gains and will search for their optimal value in three dimensional search spaces. The PSO algorithm convergence to a global optimal solution is controlled by the objective function. In order to confirm the efficient of the proposed objective function in the PSO-PID controller of DC servomotor position control is tested. **Figure (4)** show the step response of DC servomotor without PID controller.

The simulation result shown in **Figure (5)** was achieved using objective function defined by equation (15). That showed IAE performance criteria have a good response comparative to the others as listed in **Table (2)**. From **Figure (6)** the PSO-PID controller was tested using proposed objective function defined by equation (17) and results can be concluded in **Table (3)**. It can be obviously seem that the performance criteria (ITAE*W (k)) has lowest maximum overshoot and shortest of rise and settling time. To emphasize the robustness of the proposed controller, a comparison is made with the different control schemes used by researchers and listed in **Table (4)**. From previous results, the proposed objective function support PSO algorithm to reach optimal location of particles accurately than common objective function and indicates the capability of proposed controller in position tracking of DC servomotor. To validate of proposed controller we test it by pulses input. **Figure (7)** and **Table (5)** shows that the capability of controller to actuate desired response compared to traditional method Zeigler-Nichols.

CONCLUSION

The design of PSO-PID is proposed in this paper and has been successfully suggested for position tracking control of DC servomotor problem. A new objective function is proposed to help the PSO algorithm to find optimal PID controller parameters set of DC servomotor drive. Through simulation results, we could see the proposed objective function can perform an accurate PID parameters set than the other methods and can improve the dynamic performance of system.

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Table (1): Mathematical description of different performance criteria [6]

Performance Criteria	Symbol	Mathematical description of the error
Integral of the Square of the Error	ISE	$J_{ISE} = \int_0^T e^2(t)dt$
Integral of Absolute Magnitude of the Error	IAE	$J_{IAE} = \int_0^T \lvert e(t)\rvert dt$
Integral of Time multiplied by Absolute Error	ITAE	$J_{ITAE} = \int_0^T t\lvert e(t)\rvert dt$

Table (2): Step response characteristics using equation (15)

#	Max. overshoot %	Rise time (sec)	Settling time (sec)
IAE	2.6	0.0211	0.0793
ISE	5.74	0.0228	0.105
ITAE	4.21	0.025	0.107

Table (3): Step response characteristics using equation (17)

#	Max. overshoot %	Rise time (sec)	Settling time (sec)
IAE*W	8.65	0.0676	0.233
ISE*W	8.9	0.0695	0.238
ITAE*W	1	0.02	0.0423

Table (4): Comparison of different control schemes

#	Max. overshoot %	Rise time (sec)	Settling time (sec)
GA-PID [2]	1	0.25	0.336
GA-PID [6]	1	0.1	0.1
SMC [3]	0	--	0.16
ZN-PID	25.8	0.121	0.698
PSO-PID	1	0.02	0.0423

Table (5): PID gain values

#	ZN-PID	PSO-PID
K_P	50.435	50.001
K_I	13.7703	2.001
K_D	0.41743	2.05

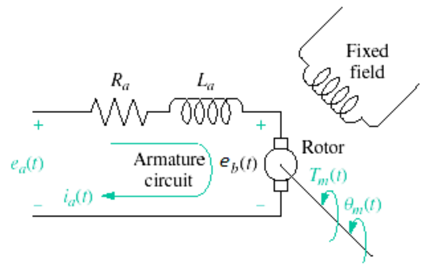

Figure (1): Equivalent circuit of armature control of DC servomotor

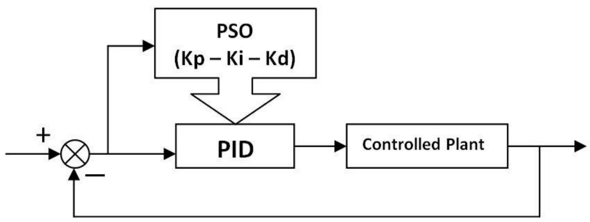

Figure (2): PSO-PID controller

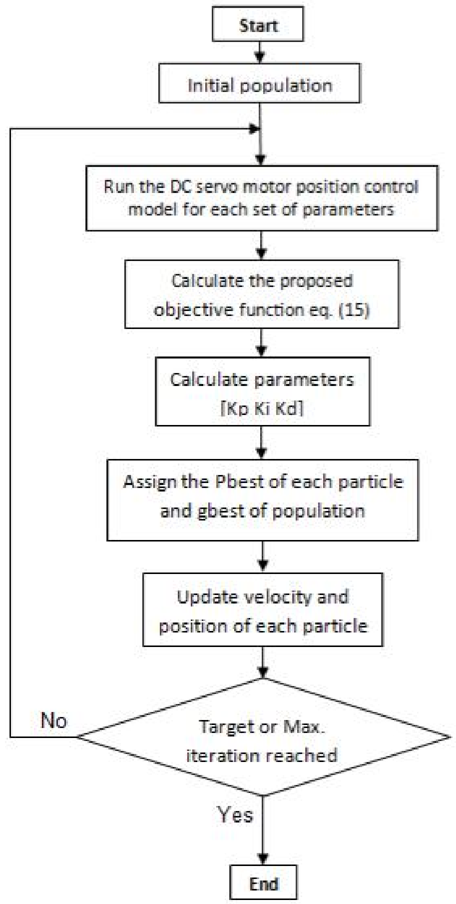

Figure (3): PSO-PID algorithm flowchart

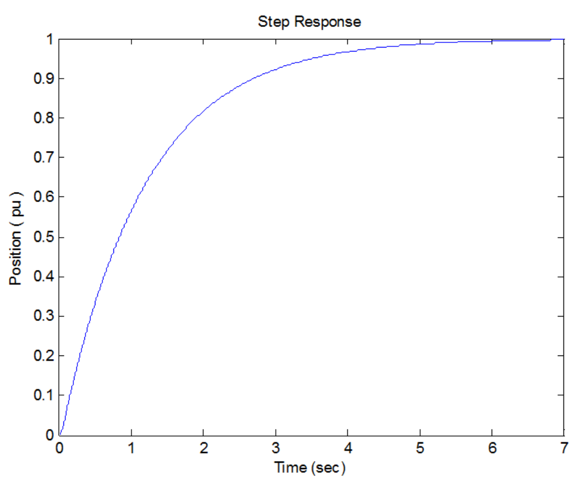

Figure (4): DC servo motor step response

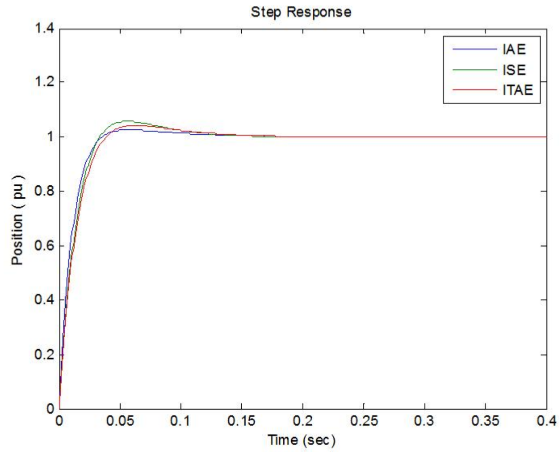

Figure (5): position step response of DC servo motor using common performance criteria

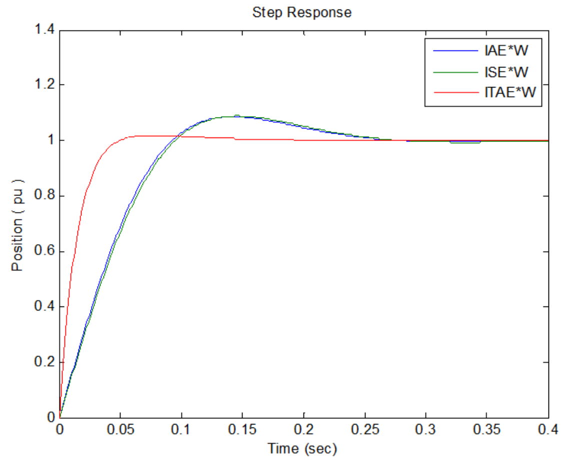

Figure (6): Position step response of DC motor using proposed objective function

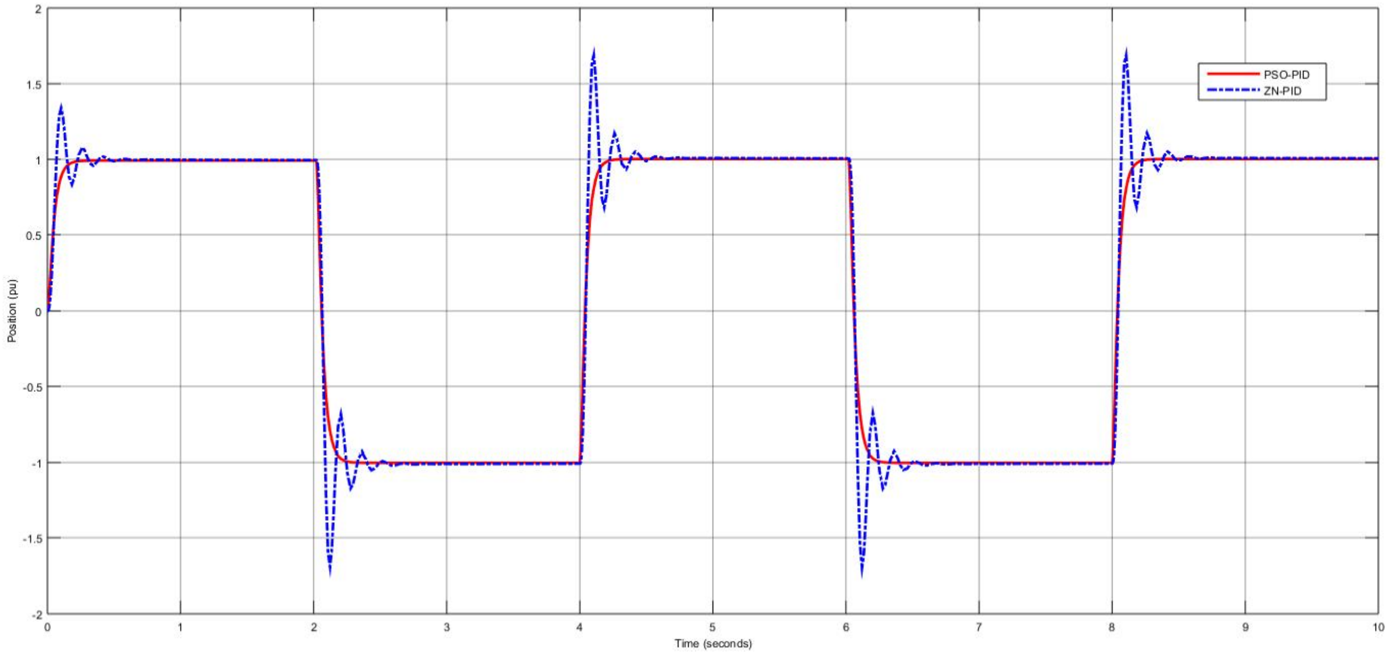

Figure (7): DC servomotor response to step change of input reference

Appendix:

DC servomotor parameters are:
V = 240 Volt.
P = 4.7 Hp.
J = 0.022 kg m^2/sec^2.
B = $0.5x10^{-3}$ Nm/sec.
K_T = 1.2 Nm/Amp.
K_b = 0.12 V/(rad/sec).
R_a =2.45 Ω.
L_a = 0.035 H.