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PID Controller Tuning Optimization for Computer Numerical Control using Particle Swarm Optimization Algorithm

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ABSTRACT

Computer Numerical Control (CNC) is a computer assisted process to control general-purpose machines according to the instructions generated by a processor from numeric instructions. Servo driving mechanism is a system that transforms the commands form NC to a linear machine motion. It can consist of a motor and a power transmission device. An artificial intelligence method Particle Swarm Optimization (PSO) algorithm is presented for determining the optimal proportional-integral-derivative (PID) controller parameters of a servo motion system used in Computer Numerical Control (CNC). This paper demonstrates in detail on how to employ the PSO method to search efficiently the optimal PID controller parameters of the servo motor. In order to assist estimating the performance of the proposed PSO-PID controller is modeled using MATLAB environment. The proposed approach yields better solution in term of rise time, settling time, maximum overshoot and steady state error condition of the system. Compared to conventional Ziegler – Nichols method, the proposed method was indeed more efficient and robust in improving the step response of the servo motor.

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Keywords- Computer Numerical Control (CNC), PID controller, Particle Swarm Optimization (PSO)

INTRODUCTION

There are many different types of CNC machine tools, which can be divided into two main groups: cutting machines and non-cutting machines. Cutting machines perform removal process to make a finished part. Examples of such machines are a milling machine and a turning machine. Noncutting machines apply force to a blank material to change the shape of the blank material. A good example of this type of a machine is a press machine. Also welding, painting, and cutting robot systems can be classified as CNC machine tools. Servomotor is an automatic device that uses error sensing feedback to correct the performance of a mechanism.

The term correctly applies only to the systems where the feedback or error correction signals help to control mechanical position or other parameters. A common type of servo provides position control. Servos are commonly electrical or partially electronic in nature, using an electric motor as the primary means of creating mechanical force. PID controllers used in most applications to stabilize the system and get the required closed loop responses. This is due to its robust nature and wide operating range. In spite of this, When PID controller is used to control servomotor used in CNC system some obstacles appear such as behaviors in terms of nonlinearity, time response, adjusting parameters based on online changes and lastly

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engineering goals such as cost and reliability. Therefore, an optimization algorithm is needed to find the optimal tuning parameters.

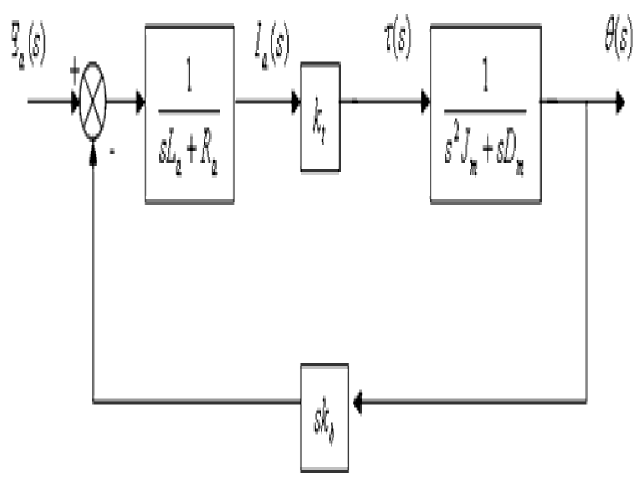
PID CONTROLLERS:

A proportional–integral–derivative controller (PID controller) is a generic control of feedback mechanism widely used in industrial control systems. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. The PID controller calculation algorithm involves three separate constant parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve, a damper, or the power supplied to a heating element. In the absence of knowledge of the underlying process, a PID controller has historically been considered the best controller. By tuning the three parameters in the PID controller algorithm, the controller can provide control action designed for specific process requirements.

Servo Motor Modeling:

Servomotor is used for position or speed control in closed loop control systems. The equivalent circuit diagram of servomotor is presented in Figure 1. The armature is modeled as a circuit with resistance Ra connected in series with an inductance, La and a voltages source Vb(t) representing the back emf in the armature when the rotor rotates.

Kirchhoff's voltage law is used to map the armature circuitry dynamic of the motor. Thus, assume the inductance La can be ignored, which in the case for servomotor. the supply voltage Ea(t) will be



Ea(t)=Ia(t)Ra+Vb(t)

Figure 1: equivalent circuit diagram of servomotor

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The transfer function between the input voltage Ea(s) and the output θm (s) can be obtained as:

$$\frac{\theta m(s)}{Ea(s)} = \frac{KT}{JmRaS^2 + (BRa + KTKB)s}$$

The parameters for used servomotor are:
KT (N.m/A) = 0.121
KB [V/(rad/s)] = 0.121
Ra (Ω) = 2.23
B [N.m/(rad/s)] = 0.0000708
Jm (kg.m2) = 0.00006286
B [N.m/(rad/s)] = 0.0000708
Substitute there parameters in the above Equation, the transfer function becomes as follow:

$$\frac{\theta m(s)}{Ea(s)} = \frac{3.839}{0.004S^2 + 0.34s + 1}$$

PARTICLE SWARM OPTIMIZATION ALGORITHM:

The algorithm proposed by Eberhart and Kennedy (1995) uses a 1-D approach for searching within the solution space. For this study the PSO algorithm will be applied to a 2-D or 3-D solution space in search of optimal tuning parameters for PI, PD and PID control[19]. Consider position i s ,n. of the i-the particle as it traverses a n-dimensional search space: The previous best position for this i-th particle is recorded and represented as pbesti,n . The best performing particle among the swarm population is denoted as gbesti,n and the velocity of each particle within the n-th dimension is represented as i n v , . The new velocity and position for each particle can be calculated from its current velocity and distance respectively.

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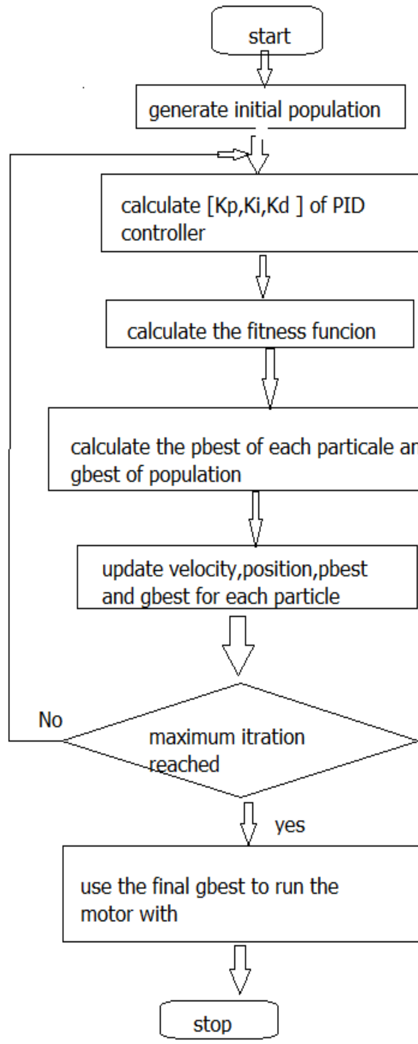

Figure 2: PSO algorithm flow chart

Scheduling PSO for PID Controller Parameters: In this paper, the PSO is used to find the optimal PID parameter's values that is used to control the servomotor. The structure of the PID controller with PSO algorithm is shown in Fig3.

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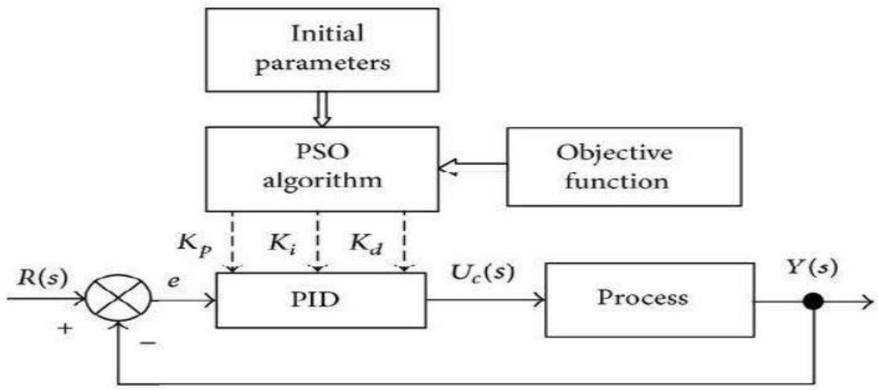

Figure 3: PID controller with PSO algorithm

The main steps in the particle swarm optimization and selection process are described as follows:
(a) Initialize a population of particles with random positions and velocities in d dimensions of the problem space and fly them.
(b) Evaluate the fitness of each particle in the swarm.
(c) For every iteration, compare each particle's fitness with its previous best fitness ($pbest$) obtained. If the current value is better than $pbest$, then set $pbest$ equal to the current value and the $pbest$ location equal to the current location in the d-dimensional space.
(d) Compare $pbest$ of particles with each other and update the swarm global best location with the greatest fitness ($gbest$). (e) Change the velocity and position of the particle According to the equations. (f) Repeat steps (a) to (e) until convergence is reached based on some desired single or multiple criteria.

5. TUNING OF PID CONTROLLER:

The PID controllers have been widely used for speed and position control. Among the traditional tuning methods, Zigler_Nichols method has been the most used. For a wide range of applications, this technique worked quite well, however, sometimes it does not provide the optimum tuning and tend to produce a big overshoot especially for CNC machines. To enhance the capabilities of the traditional PID parameter tuning technique, several intelligent approaches have been suggested to improve the tuning. Such as Genetic Algorithm (GA) and particle Swarm Optimization (PSO). These methods are used to find the optimal performance. The proportional part of the PID is used to reduce error response to disturbances. The integral part is used to eliminate steady-state error and the derivative term error dampens the dynamic response and improves the stability of the system. In the design of the PID controller the three gain parameters must be selected in a way that the closed loop system has to give the desired response which should have minimal settling time with small or no overshoot in the step response of the closed system loop.

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RESULTS

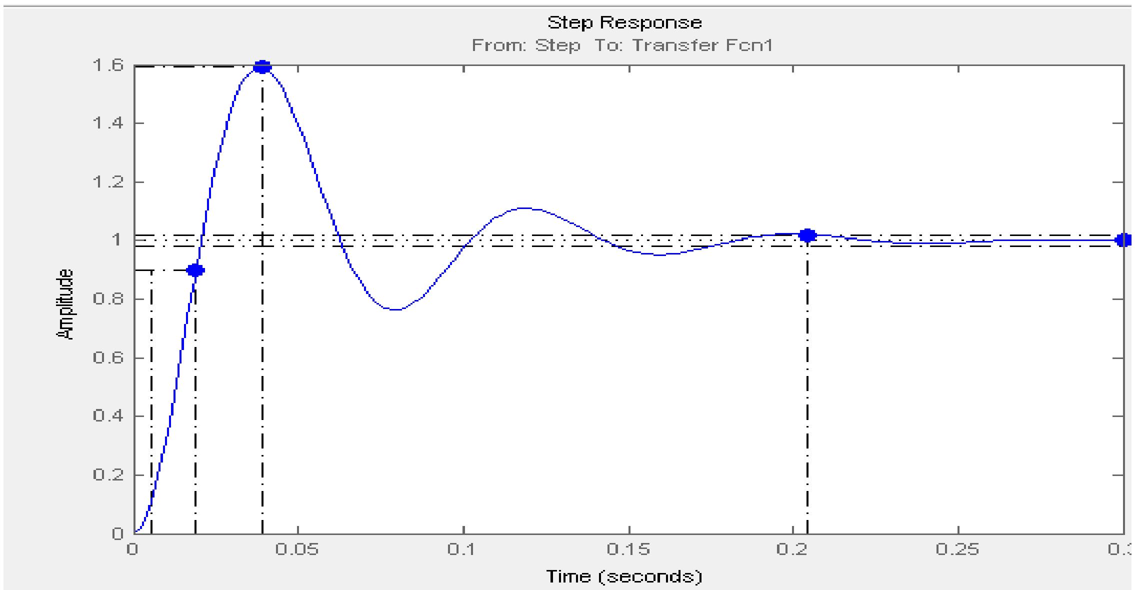

Figure 4: step response of PI controller Kp=11.622 and Ki=409.03439

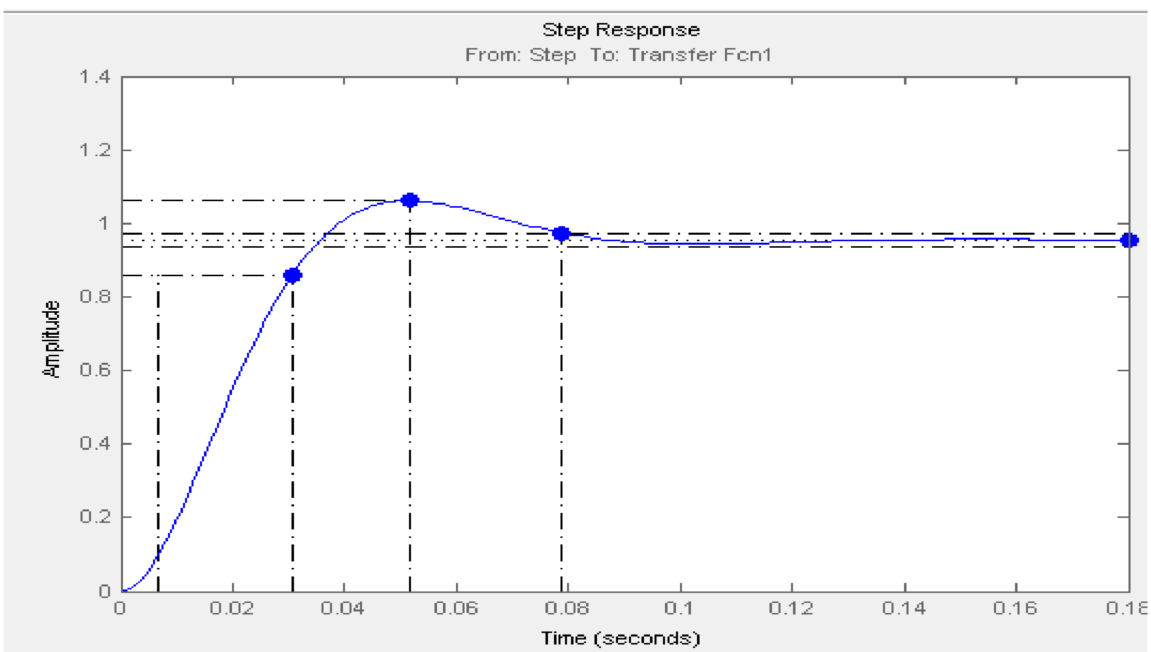

Figure 5: step response of PD controller Kp=27.9380 and Kd=0.16194

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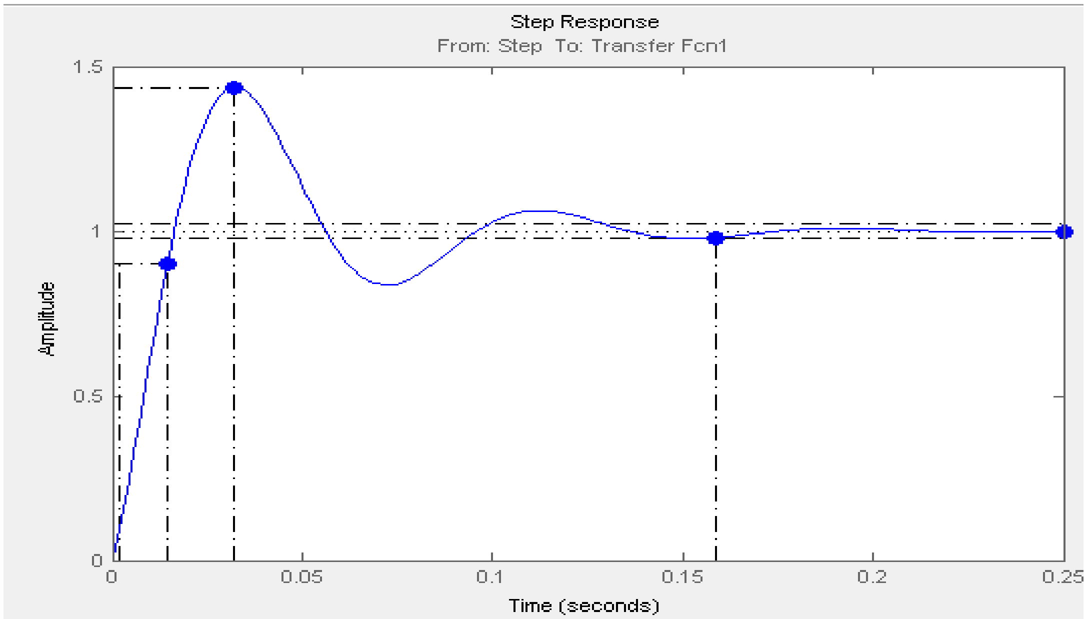

Figure 6: Step response of PID using Z-N method calculated using MATLAB. Kp=15.4966 Ki=818.0687 and Kd=0.07338

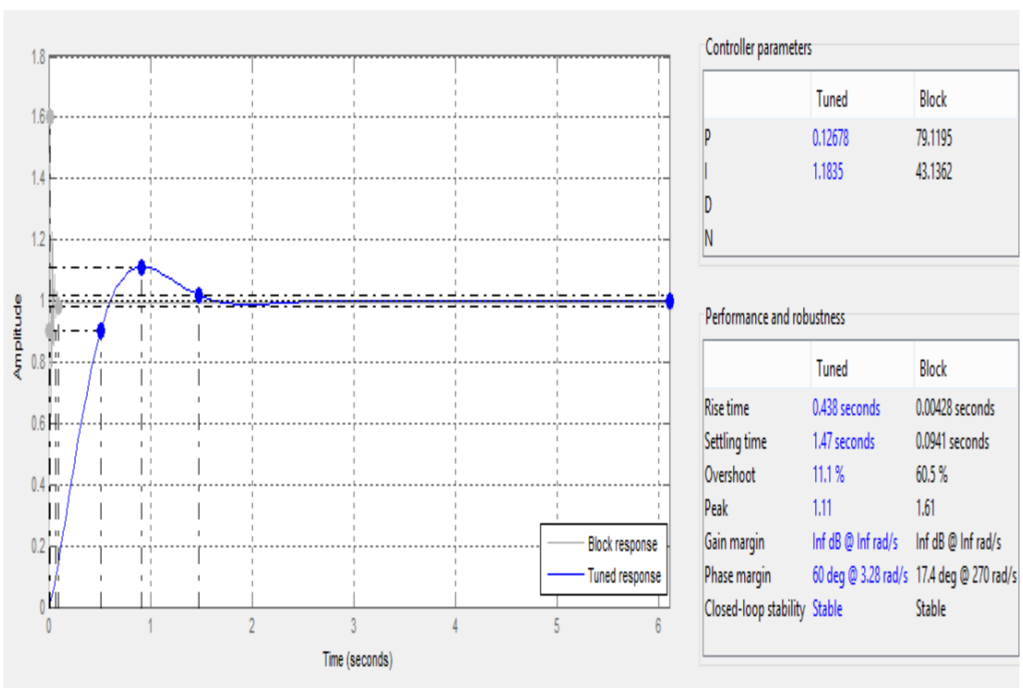

Figure 7: step response of PSO-PI controller

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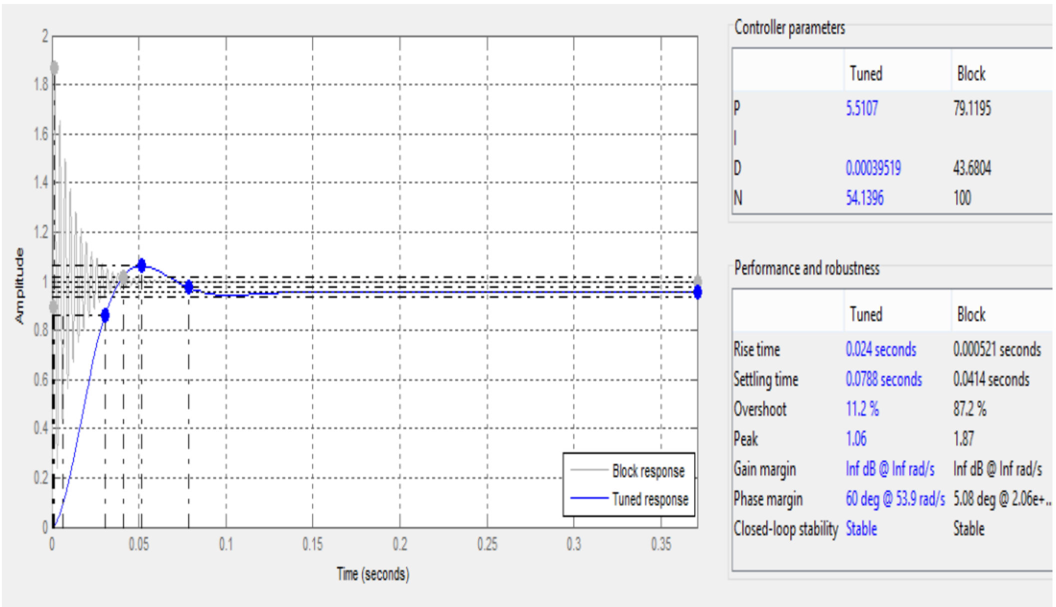

Figure 8: step response of PSO-PD controller

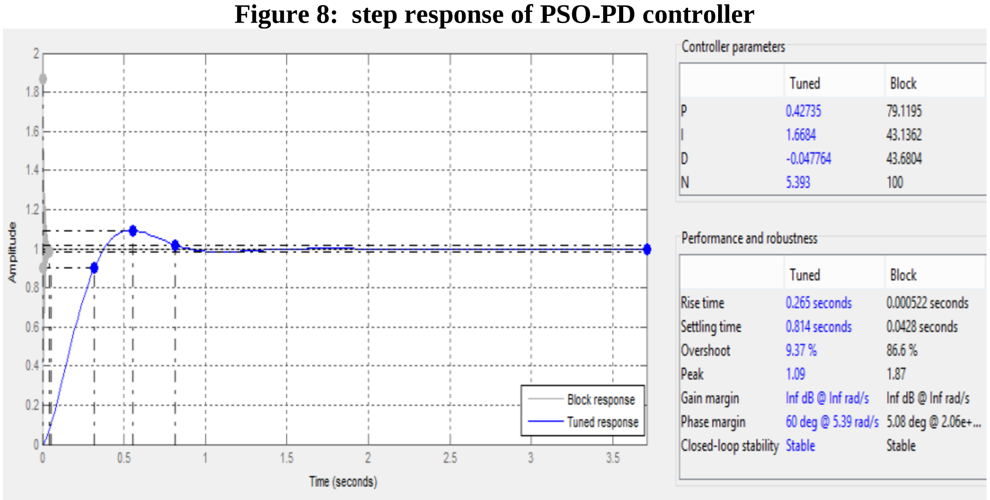

Figure 9: step response of PSO-PID controller

Table 1: comparison between, PSO-PI, PD and PID

	Rise time(Sec)	Settling time(sec)	Overshoot (%)	Overshoot time (sec)
PI	0.00428	0.0941	60.5%	0.012
PD	0.000521	0.0414	87.2%	0.00152
PID	0.000522	0.0428	86.6%	0.00152

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Table 2: comparison between, PSO- PID and Z-N maximum rise time, settling time and overshoot

PID parameters	Rise time (sec)	Settling time (sec)	Overshoot) %)	Overshoot time (sec)
Z-N	0.0122	0.155	43.4	0.0326
PSO	0.00522	0.0428	86.6	0.00152

CONCLUSION

PID controllers are a widespread control solution due to their simple architecture, generally acceptable control performance and ease of use. In this work PID controller has been tuned using Ziegler-Nichols method and Particle Swarm Optimization (PSO) through simulation of servo motor speed control system. The performance of the PSO algorithm method of tuning a PID controller has been proved better than traditional method Ziegler-Nichols method, in terms of the system settling time and rise time. Although the overshoot of the PSO seems to have larger percentage than Z-N, but the overshoot time is very small that can be neglected. So PSO has proved a better result in term of overshoot as well.

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