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Tuning of PID Controller for Time Delayed Process Using Particle Swarm Optimization

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Abstract— This paper proposes PID controller tuning for time delayed process using particle swarm optimization. There is a need to control the process with time delay in many industries. Presence of dead time in control system makes the system uncertain and gives large overshoot. When the time delay becomes longer compare to system time constant, or when the time delay varies, then control of such system becomes very difficult by classical tuning method. However many techniques of PID controller tuning came in existence in recent years which gives better results compare to classical tuning rule that is Ziegler Nichols Tuning method. This paper presents a new scheme for tuning of PID controller with time delay process. Particle swarm optimization is the topic of recent research and many researchers are working on it. It is a population based technique which is inspired by the social behavior of biological organism. It is an efficient and fast tuning scheme compare to other conventional techniques. This paper presents simulation results of time delayed process using PSO and a comparison with Ziegler Nichols tuning method.

Index Terms— **Particle Swarm Optimization, social behavior, swarm intelligence, Time delayed process.**

I. INTRODUCTION

Time delays are usually unavoidable in many mechanical and electrical systems. The presence of delay in the system imposes limits on its feedback performance. Time delay is the time interval between the start of an event at one point and its resulting action at another point in the system. Time delay is also known as dead time, which can be present in physical, chemical and biological system, as well as in the process of measurement and computation. Time delays are present in the system dynamics either due to the nature of the system itself or may be incurred due to delayed measurements. Systems incorporating delays in the system under study or in the control loops are known as Time Delay Systems. When there is any propagation or transmission of information in a system then it is certain for the delay to occur. The presence of delay in the system makes the analysis of the system complicated [II].

The system analysis and design becomes complicated in the presence of time delay. In system without delays, the response to any error in the output can be encountered directly by applying a change in the input. However, in a time-delay system the effect of applying any change in the input will occur at the output after an inherited delay [III]. Delays always reduce stability of the system. Hence it becomes important to study the delay in order to improve the error resulting from it. When the delay is present in the measuring device then the controller may not receive the information in the right time whereas if the delay is present in the actuating device then the efficiency might decrease as a result of application of control signal in the wrong time [IV]. When the delay exists in the internal state, in addition to the previous pitfalls associated with the delay, it also changes dynamic behaviour of the system considerably from the behaviour of delay-free systems [V]. If the delay exists in the feedback loop, it can be considered as disturbances. This might result in significant and immediate change in the slope of the system step- response. Hence, the response of system with feedback delay is usually not smooth [VI].

Most of the classical methods used in controller design cannot be used with time delayed process. However there are different approaches to model the time delay such as Smith predictor and Pade approximation method [VII].

Smith predictor was firstly introduced in 1950's. It is still fundamental tool for modeling systems with time delay [VIII]. Smith predictor can only be applied for sable system, modified Smith predictor can be used in modeling of unstable system. After modeling classical PID control can be used [IX].

PID controller is widely used in process industries. Reason behind the popularity of PID controller is its simplicity, robustness and satisfactory performance. Because of their widespread use in industries many techniques have been proposed by researchers to tune the parameters of PID controller [I]. The parameters of the PID controller can be tuned by many tuning schemes such as trial-and-error tuning, empirical tuning like the well-known Ziegler–Nichols method, analytical tuning, prediction approach tuning, IMC tuning and so on. In 1942 Ziegler and Nichols proposed a tuning rule for

PID controller. Although it lacks the parameter selection and produce big overshoot in time response, still it is used by many industries to tune the parameters.

A new tuning approach "Particle swarm optimization" has been introduced in this paper for tuning of PID controller with time delay process. PSO was first introduced by Dr. J. Kennedy and R. C. Eberhart in 1995 [X]. Particle swarm optimization is population based technique which is inspired by the social behaviour of biological organism. It is an efficient and fast tuning scheme for solving nonlinear large scale optimization problems.

This section of paper presents brief introduction about time delayed process, section II contains mathematical model of time delayed process, section III describe conventional Ziegler Nichols tuning method, section IV describes proposed scheme of PID tuning, section V contains PSO based time delayed process, section VI presents simulation results and comparisons and finally section VII contains conclusion.

II. MATHEMATICAL MODEL OF TIME DELAYED PROCESS

The model has been used here is second order plus time delay system described by Seborg et al. [XII].

$$G_p(s) = \frac{2e^{-s}}{(10s+1)(5s+1)} \qquad (1)$$

PID controllers were designed for this model based on Ziegler Nichols method. In the proposed work particle swarm optimization is used for design PID controller.

III. ZIEGLER NICHOLS TUNING METHOD

The most well known formula for tuning of PID controller was given by Ziegler and Nichols in 1940's. This method is applied to first order plant with transportation delay. The step response is characterized by two parameters, L the time delay and T the time constant. These parameters are found by drawing a tangent to the step response at the point of inflection and noting its intersections with the time axis and steady state value. Therefore the plant model is given by [XIII]:

$$G_p(s) = \frac{ke^{-sL}}{Ts+1} \qquad (2)$$

The values of control parameters can be found from the sketch of the response of Ziegler Nichols method which is shown in fig.1.

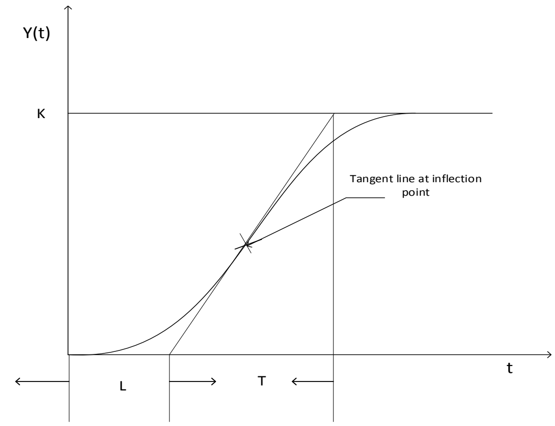

Fig.1. Response curve for Ziegler Nichols Method

with L and a the Ziegler Nichols formula Table I can be used to gain PID controller parameters, where a=kL/T.

TABLE I
ZIEGLER NICHOLS TUNING METHOD

	Kp	Tr	Td
P	0.50Kc		
PI	0.45Kc	Pc/1.2	
PID	0.60Kc	0.5Pc	Pc/8

where
Kp =Kc = Ultimate gain
Ki = Kp/Tr
Kd = Kp*Td
Pc = Ultimate period of oscillation

IV. OVERVIEW OF PARTICLE SWARM OPTIMIZATION

Particle swarm optimization is population based approach. It was proposed in 1995 by Dr. Eberhart and Dr. Kennedy [X] which was originally inspired by the social behaviour of biological organism. Attractive features of PSO are, it is easy to implement and no gradient information is required. It can be used to solve wide range of complex optimization problems. PSO usually initializes a population of particles that fly through the problem hyperspace with the associated velocities. Particles move in the problem hyperspace and update their velocity and position according to the historical best position of particle itself and previous best position of neighbourhood particle. Best position of particle and its neighbourhood particle is derived according to the user defined fitness function which is evaluated for each particle in the swarm. Algorithm of original PSO include following steps [XIV]:

1) Initialize the swarm by assigning random position to each particle.

2) Assign velocities to each particle in the interval [-v_{max}, v_{max}].
3) Evaluate fitness function for each particle in the swarm.
4) Compare the current fitness value with the pbest value of the particle in history.
5) If current fitness value is better than the previous best value (pbest), then set this value as current pbest.
6) Now best evaluated value of pbest is set as gbest value.
7) Update the velocity and position of the particles according to the equation (3) and (4).
8) Repeat the steps 2 to 6 until sufficiently good stopping criterion is met such as maximum number of iterations or best fitness value.

Update in particle's velocities and positions are given by following equations:

$$v_{n,d}^{k+1} = w * v_{n,d}^{k} + c1 * r1 * \left(pbest_{n,d} - x_{n,d}^{k}\right) + c2 * r2 * \left(gbest_{d} - x_{n,d}^{k}\right) \quad (3)$$

$$x_{n,d}^{k+1} = x_{n,d}^{k} + v_{n,d}^{k+1} \quad (4)$$

n=1,2,.....,N , d=1,2,........,D and k=1,2,.....,T

where,

N Number of particles
D Dimension of the problem space
T Maximum number of iterations
$v_{n,d}^{k+1}$ Velocity of n^{th} particle with dimension d at iteration k+1
if $v_{i,j}^{(k)} > v_{max}$ then $v_{i,j}^{(k)} = v_{max}$
else if $v_{i,j}^{(k)} < -v_{max}$ then $v_{i,j}^{(k)} = -v_{max}$
$x_{n,d}^{k}$ Current position of n^{th} particle with dimension d
c1,c2 Acceleration factors
r1,r2 Random numbers between [0,1]
$pbest_{n,d}$ Personal best value of n^{th} particle with dimension d
$gbest_{n,d}$ Global best value of swarm
w Inertia weight

Initially the value of weighting factor 'w' was constant. Researchers also suggested that this weighting factor could be dynamic throughout the optimization process, starting with the value greater than 1 and decreasing eventually to a value less than 1 so later on it was kept linear from 0.9 to 0.4.Inertia weight 'w' is given by [XI]:

$$w = w_{max} - \left(\frac{w_{max} - w_{min}}{itermax}\right) * iter \quad (5)$$

where w_{max}= 0.9 and w_{min}= 0.4

Velocity update equation is determined by three terms [XV]:

1) Momentum: is previous velocity and is responsible to carry the particle in the same direction, it has been travelled.
2) Cognitive component: is tendency of particle to move towards personal best position ever visited by particle.
3) Social component: is tendency to move towards best position in the swarm.

V. PSO BASED TIME DELAYED PROCESS

A. Selection of PSO parameters:

Particle swarm optimization algorithm is population based technique so first of all we have to produce initial swarm of particles in search space represented by a matrix of dimension swarm size x 3. Three parameters are there to be tuned where their values are set in the range of 0 to 100. For this three dimensional problem position and velocity are represented by matrices of dimension swarm size x 3. Swarm size is the number of particles, 30 considered here for the problem. Maximum number of iterations 50 has been used here.

B. Objective function:

The objective function which has been used here is error criteria. Performance of controller is based on error criterion or performance index. Commonly employed performance indices are:

1) Integral of Absolute Errors, given by

$$J_{IAE} = \int_0^\infty |e(t)|dt \quad (6)$$

2) Integral of Squared Errors, given by

$$J_{ISE} = \int_0^\infty e^2(t)dt \quad (7)$$

3) Integral of Time multiplied by Absolute Errors

$$J_{ITAE} = \int_0^\infty t|e(t)|dt \quad (8)$$

VI. SIMULATION RESULTS AND COMPARISON

Analysis shows that design of the proposed controller gives better results than conventional technique. Simulation results show improved performance of the system response in time domain. Using the PSO approach global optimal solution could be found for better tuning of the controller parameters. PID controller parameters for both tuning methods are shown in Table II.

TABLE II : PID CONTROLLER PARAMETERS FOR TIME DELAYED PROCESS

Controllers	ZN	PSO
Proportional gain(kp)	4.72	3.58
Integral gain(ki)	0.80	0.29
Derivative gain(kd)	6.89	13.6

A comparative step response of time delayed process is shown in fig.2

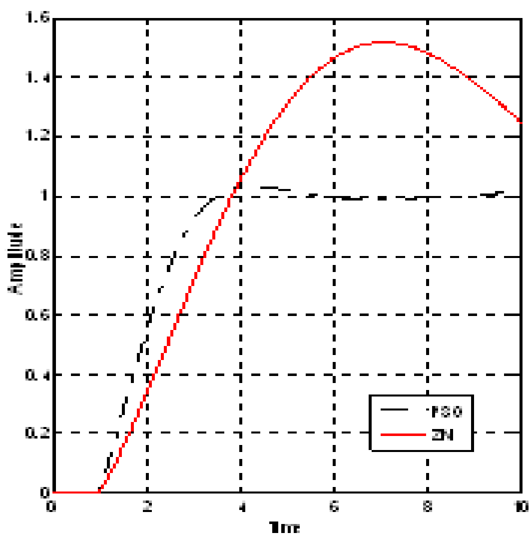

Fig.2. Comparative Response of PSO and ZN based Controller for time delayed process

The Response curve with the Ziegler Nichols tuned controller has a big overshoot and delay is not taken care properly, whereas PSO based controller gives better response.

Based on these responses time domain specifications of time delayed process controlled by both the techniques are tabulated in Table III. Comparison of time domain specifications such as overshoot, rise time and settling time shows the effectiveness of proposed scheme.

TABLE III : COMPARISON OF TIME DOMAIN PERFORMANCE SPECIFICATIONS

	ZN	PSO
Peak overshoot (%)	51.6	3.28
Rise time (sec)	2.2	1.76
Settling time (sec)	33.5	20.12

The robustness investigation for the time delayed process is analyzed by calculating the performance index, which is shown in fig.3.

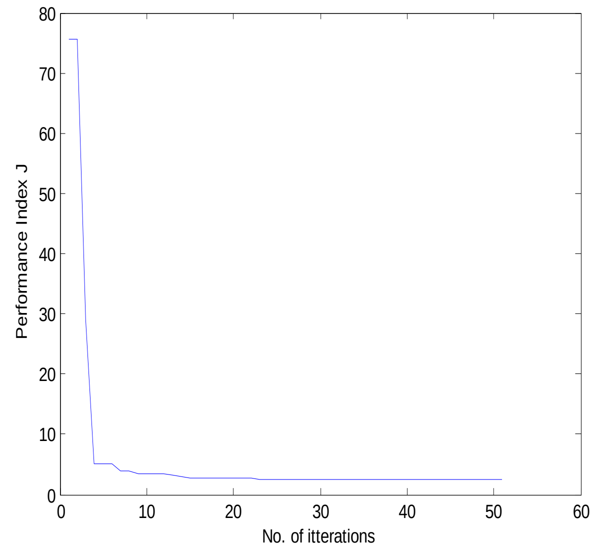

Fig.3. ITAE values for 50 iterations for PSO based time delayed process

The calculation of different performance indexes for bothh tuning scheme is given in Table IV.

TABLE IV
COMPARISON OF PERFORMANCE INDICES

	ZN	PSO
ITAE	20.12	2.61
IAE	4.79	2.85
ISE	2.98	1.46

VII. CONCLUSION

The various results presented above prove that PSO is better technique of PID tuning than Zeigler Nichols tuning method. Simulation results for the models show the effectiveness of the proposed scheme. Form the time domain specifications it has been proved that PSO based system produce less overshoot, reduce the rise time and settling time. PSO requires less amount of information for controller tuning. The performance index under the entire error criterion is always less for the proposed controller.

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