GENERALIZED PID CONTROLLER BASED ON PARTICLE SWARM OPTIMIZATION[1]

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Abstract

The paper presents the novel application of Particle Swarm optimization (PSO) for the optimal tuning of the new PID controller which is called generalized PID (GPID). In 2009, Zhao Xiaodong, Li Yongqiang , Xue Anke *proposed a* generalized PID*(GPID)* to improve the time response and control quality of the traditional PID control algorithm This paper applies the Particle Swarm Optimization(PSO) algorithm for GPID controllers. The main goal is to eliminate the steady state error of the system and minimize the error performance index. The method searches the GPID parameter that realizes the expected step response of the plant. The expected response is defined by the overshoot ratio, the rising time, the settling time. The numerical result and the experiment result show the effectiveness of the proposed tuning method when the results are compared with the Traditional PID Controller.

Keywords: GPID, PID, Particle Swarm Optimization, Tuning Algorithm.

مسيطرات ال GPID اعتمادا على أمثلية حشد الجزيئة

الملخص

يقدّم هذا البحث تطبيق لتحقيق أمثلية حشد الجزيئة (PSO) للتضبيط المثالي لنوع جديد من المسيطرات هو .GPID في سنة 2009 اقترح الباحثين Zhao Xiaodong, Li Yongqiang , Xue Anke نوع جديد من مسيطرات ال PID يسمى GPID لتحسين الاستجابة وكذلك نوعية السيطرة مقارنة بالمسيطرات التقليدية. يطبق هذا البحث أمثلية حشد الجزيئة (PSO) على النوع الجديد من المسيطرات. الغاية الرئيسية هي التخلص من الخطأ في الحالة المستقرة وتحسين استجابة النظام في الحالة المؤقته.حيث تقوم طريقة PSO بالبحث عن افضل معاملات لل GPID للحصول على اقل خطأ واصغر مايمكن للقيمة العظمى,وقت الارتفاع, و وقت الاستقرار.لقد اثبتت الطريقة المقترحة من خلال اجراء الاختبارات نجاح الطريقة المقترحة مقارنة بالمسيطرات العادية.

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1- Introduction

Conventional proportional–integral–derivative (PID) controllers have been well developed and applied for about half a century, and are extensively used for industrial automation and process control today. The main reason is due to their simplicity of operation, ease of design, inexpensive maintenance, low cost, and effectiveness for most linear systems. Motivated by the rapidly developed advanced microelectronics and digital processors [1,2], the study of new generation of PID controllers has drawn significant attention in recent years . Specifically, Zhao Xiaodong, Li Yangquan , Xue Anke propose a generalized PID algorithm (GPID) is to improve the time response and control quality of the traditional PID control algorithm.

The traditional PID controller is a special case of the generalized PID; this can be shown by comparing the coefficients of GPID and PID. GPID can be obtained by adding higher-order derivative terms in the form of the traditional PID [3] .The tuning method based on PSO (Particle Swarm Optimization) has already been proposed to obtain the optimal PID parameter. This method has not considered the step response of constraints (the overshoot ratio, the rising time, the settling time and so on). This paper presents a new method that obtains the PID parameter realizing the expected step response with the constraints. A proposed method using Particle Swarm Optimization (PSO) is implemented into the GPID tuning tool on a personal computer. The developed tool provides the GPID parameter that realizes the expected step response of the plant. The numerical result and the experimental result show the effectiveness of the proposed new GPID parameter tuning method.

2- Background

2.1- PID Controller

The PID controller is a linear controller. Fig.1 illustrates the core architecture of a PID controller. The PID controller calculation (algorithm) involves three separate parameters; the Proportional, the Integral and Derivative values. The Proportional value determines the reaction to the current error, the Integral value determines the reaction based on the sum of recent errors, and the Derivative value determines the reaction based on the rate at which the error has been changing. 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 or the power supply of a heating element. The normal PID controller is in the following form [3]

$$u(t) = k_p e(t) + k_i \int e(t)dt + k_d de(t)/dt \quad \text{.......(1)}$$

where $e(t) = r(t) - y(t)$ is the error between reference input and output. By "tuning" the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements

2.2- Generalized PID Controller

Based on the study of traditional PID controller, in 2009 Zhao Xiaodong, Li Yongqiang , Xue Anke *proposed* generalized PID*(GPID) by* increasing higher order derivatives terms, In (1), a second order derivative term of e(t) is added, we can get:

$$u(t) = k_p e(t) + k_i \int e(t)dt + k_d de(t)/dt + k_a d^2 e(t)/dt^2 \quad \text{........(2)}$$

As the physical meaning of the derivative, the first derivative represents the change speed of the error, the second derivative represents the acceleration of the error. In (2), the second derivative added restrains the acceleration of the error getting bigger and makes the system's response quicker and reduce the overshoot, increase the stability of the system. Thus the controller gains better control effect. However, increasing higher-order derivative also makes some problems, such as increasing the time and the difficulty of setting the parameter and amplifying the noise interference.

3- Particle Swarm Optimization (PSO)

Optimization algorithms are another area that has been receiving increased attention in the past few years by the research community as well as the industry. An optimization algorithm is a numerical method or algorithm for finding the maxima or the minima of a function operating with certain constraints [5].

Particle swarm optimization (PSO) is a relatively recently devised population-based stochastic global optimization algorithm. PSO has many similarities with evolutionary algorithms, and has also proven to have robust performance over a variety of difficult optimization problems. However, the original formulation of PSO requires the search space to be continuous and the individuals to be represented as vectors of real numbers [6]

Particle swarm optimization originally relates to artificial life (Alife) in general and specifically it connects with bird flocking and fish schooling. The Intelligence in PSO as any other swarm technique is a collective intelligence resulting in the collective behaviors of (unsophisticated) individuals interacting locally and with their environment causing coherent functional global patterns to emerge. Particle Swarm Optimization (PSO), inspired by the social behavior of bird flocking or fish schooling and Ant Colony Optimization (ACO) inspired by the behavior of ants are the primary computational parts of swarm intelligence. In 1995, Kennedy and Eberhart first introduced the particle swarm optimization (PSO) method as a stochastic, population-based evolutionary algorithm for problem solving. The key idea of PSO method is to simulate the shared behavior happening among the birds flocks or fish school[7].Particle Swarm Optimization has more advantages over Genetic Algorithm as follows:

(a). PSO is easier to implement and there are fewer parameters to adjust.

(b). In PSO, every particle remembers its own previous best value as well as the neighborhood best ; therefore, it has a more effective memory capability than GA.

(c).PSO is more efficient in maintaining the diversity of the swarm, since all the particles use the information related to the most successful particle in order to improve themselves, whereas in Genetic algorithm, the worse solutions are discarded and only the new ones are saved; (i.e) in GA the population evolves around a subset of the best individuals[8].

In the PSO algorithm, instead of using evolutionary operators such as mutation and crossover, to manipulate algorithms, for a d-variabled optimization problem, a flock of particles are put into the d-dimensional search space with randomly chosen velocities and positions knowing their best values so far (Pbest) and the position in the d-dimensional space. The velocity of each particle, adjusted according to its own flying experience and the other particle's flying experience. For example, the *i* th particle is represented as

$$x_i=(x_{i,1}, x_{i,2}, x_{i,3}\ldots\ldots, x_{i,d}) \quad .(3)$$

in the d-dimensional space. The best previous position of the *i* th particle is recorded and represented as:

$$Pbest_i= (Pbest_{i,1} ,Pbest_{i,2} ,...,Pbest_{i,d}) \quad ....(4)$$

The index of best particle among all of the particles in thegroup is d $gbest_d$. The velocity for particle *i* is represented as

$$v_i=(v_{i,1}, v_{i,2}, v_{i,3}\ldots\ldots, v_{i,d}) \quad \ldots(5)$$

The modified velocity and position of each particle can be calculated using the current velocity and the distance from $Pbest_{i,d}$ to $gbest_d$ as shown in the following formulas :

$$v_{i,m}^{(t+1)} = w.v_{i,m}^{(t)} + c_1 * rand() * (pbest_{i,m} - x_{i,m}^{(t)}) + c_2 * Rand * (gbest_m - x_{i,m}^{(t)}) \quad \ldots(6)$$

$$x_{i,m}^{(t+1)} = x_{i,m}^{(t)} + v_{i,m}^{(t+1)} \quad .....(7)$$

I=1,2,….n
M=1,2,..m
Where
n Number of particles in the group
d dimension
t Pointer of iterations(generations)
$v_{i,m}^{(t)}$ Velocity of particle I at iteration t
W Inertia weight factor ,c_1,c_2 Acceleration constant
Rand() Random number between 0 and 1
$x_{i,m}^{(t)}$ Current position of particle i at iterations
$Pbest_i$ Best previous position of the ith particle
gbest Best particle among all the particles in the population. Figure 1 show the PSO Steps.

5-PSO based optimal GPID controller design

This paper describes the application of PSO to the fine-tuning of the parameters for GPID controllers. Such a simple but general approach, having ability for global optimization and with good robustness, is expected to overcome some weakness of conventional approaches and to be more acceptable for industrial practices. An improved multi-objective optimization method for parameter tuning of GPID controller based on PSO algorithm is proposed, which consists of the following two steps:

Step 1: Scheduling PSO for PID Controller parameters. In this paper, An GPID controller using PSO Algorithms to find the optimal parameters of DC Motor speed control system. The structure of the GPID controller with PSO algorithms is shown in Fig. 4. In the proposed PSO method each particle contains four members k_i ,k_p,k_d and k_a. It means that the search space has four dimension and particles must ‘fly’ in a four dimensional space.

Step 2: Design of Fitness Function

The most crucial step in applying optimization problems is to choose the objective functions to evaluate fitness of each chromosome To evaluate the

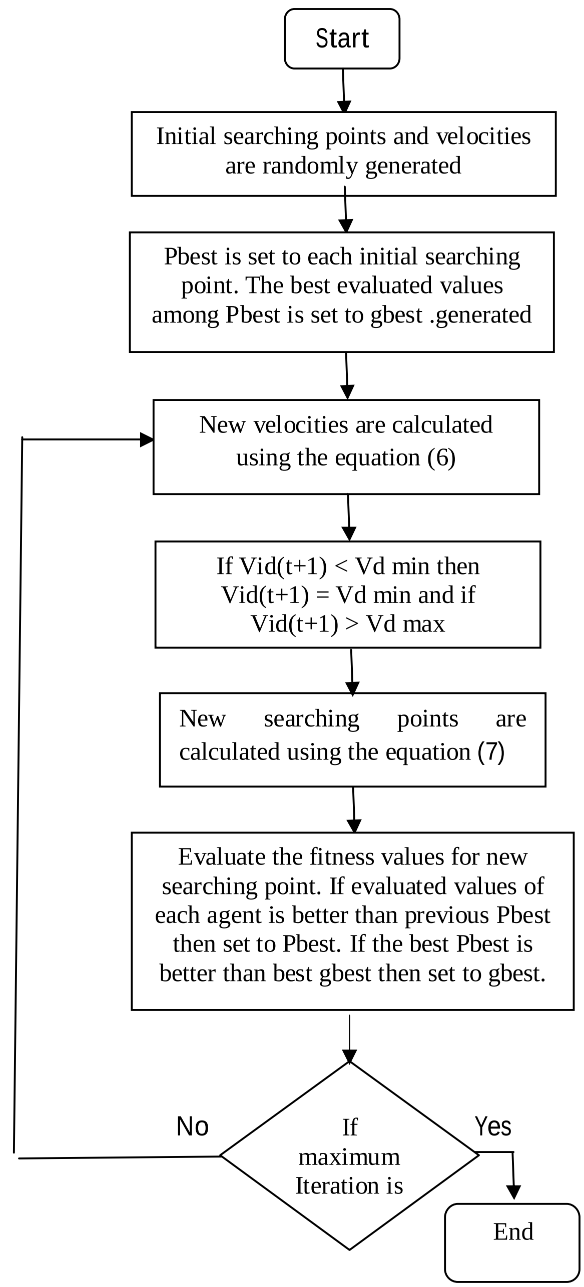

Fig. 1 PSO Algorithm

controller performance, there are always several criterions of control quality are Integral of Time multiplied by Absolute Error (ITAE), Integral of Absolute Magnitude of the Error (IAE), and Integral of the Squared Error (ISE), **[9].**

$$\left.\begin{aligned} ITAE &= \int_0^\tau t\,|e(t)|\,dt \\ ISE &= \int_0^\tau (e(t))^2\,dt, IAE = \int_0^\tau |e(t)|\,dt \end{aligned}\right\} \quad (8)$$

5.1- Multi-Objective PSO

In this paper to evaluate the controller performance and get the satisfied transient dynamic, the fitness function includes the four main transient performance indices, overshoot, rise time, settling time and cumulative error. This leads to using Multi-objective optimization in order to get the desired response

The First Objective: w_1J_1
The Second Objective: w_2t_r
The third Objective: $w_3\sigma$
The Fourth Objective: w_4t_s
Therefore the fitness function used is designed as [10]

$$J = 1 \Big/ w_1J_1 + w_2t_r + w_3\sigma + w_4t_s \quad ..(9)$$

Where J_1 is one of the control qualities (defined in eqn(8)), t_r is the rise time, σ is the maximal overshoot, t_s is the settling time with 5% error band, are weighting coefficients. One could adjust all the weighting coefficients in the fitness function based on specific requests such as rapidity, accuracy and stability of the system. For example if a system with little overshoot value is required, ω_4 would be increased appropriately; if a system with fast dynamic responses is required, then ω_3 would be increased appropriately. This research has picked the weighting coefficients w_1, w_2, w_3, *and* w_4 to cover all the performance indices completely.

6- Simulation Results

For the purpose of showing the effectiveness of the proposed method and the developed tool, numerical examples and experimental examples are studied and simulated using the MATLAB. The DC motor under study has the following parameters:
The transfer function of DC motor is

$$\frac{\theta(s)}{v(s)} = \frac{k_b}{JL_as^3 + (R_aJ + BL_a)s^2 + (k_bk_T + R_aB)s}$$

….. (10)

Where, R=Ra=Armature resistance in ohm, L=La=Armature inductance in henry ,v= Va=Armature voltage in volts ,eb= e(t)=Back emf voltage in volts, Kb=back emf constant in volt/(rad/sec), K= K_T=torque constant in N-m/Ampere, Tm=torque developed by the motor in N-m, θ(t)=angular displacement of shaft in radians, J=moment of inertia of motor and load in Kg-m2/rad, B=frictional constant of motor and load in N-m/(rad/sec) .
La=0.3e^{-3}h,J=6.52e^{-6} Kg-m^2/rad.
Ra=1.71ohm,Kt=0.0445,Kb=.0444volt/(rad/sec),B=0.5*10^-3 N-m/(rad/sec).

While The PSO parameters are listed in Table 1. Wich used to verify the performance of the PID-PSO controller parameters.

Table (1). PSO Parameters

PSO Parameters	Value
Population size	100
w_{min}	0.1
w_{max}	0.6
C1 =C2	1.5
Iteration	100

The control parameters were tuned and the simulation results are shown on the following pages. Table 2 shows the results of PSO algorithm running. The table shows the main objective function and transient specifications for the tuned GPID and tuned PID.

The PSO Gain tuning algorithm was used to minimize the absolute of controller total error as shown in figure. 2.

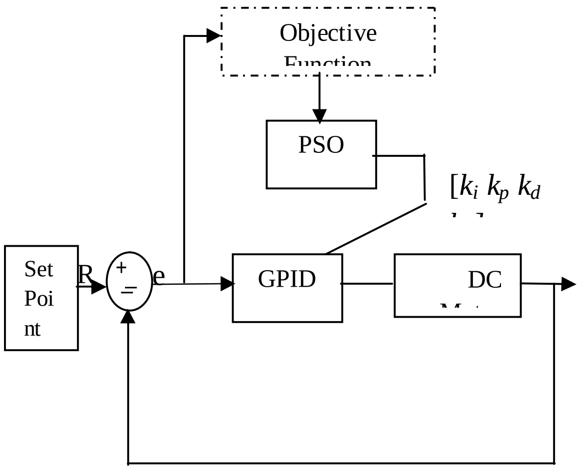

Figure (2) Close loop block diagram of a SISO system

Table (3) shows the values of the GPID, PID Controllers parameter at different objective function.

Figures 3, 4, and 5 shows the response to the step input signal with desired input (desired Position) 90 based on different tuning techniques. It has been found that the performance of the proposed is better than other technique in term of time response such as settling time, rise time and over shoot. Notice, from the step response, that the performance of the proposed technique is better than the other techniques in approach to steady state. Finally from the figures 3, 4 and 5, the response of the GPID is better than PID in all objective functions. Figure 6 shows the comparison between PSO and Genetic Algorithm (GA). It may be said that the PSO algorithm gets better performance than GA; Table (4) shows the results of this comparison.

7- Conclusions

A PSO algorithm to tun the new PID controller which is called GPID is presented in this paper. The main goal was to eliminate the steady state error of the system and minimize the performance index.

The position of a DC Motor drive is controlled by GPID-PSO controller. Obtained through simulation of DC motor; the results show that the proposed controller can perform an efficient search for the optimal PID controller. This algorithm successfully tuned the parameters for the four GPID controller parameters.

By comparison with the PID controller, it shows that the presented method can improve the dynamic performance of the system in a better way. The GPID-PSO controller is the best to present satisfactory performances and possesses good robustness (very low overshoot, minimal rise time, Steady state error = 0). The optimizing performance of the PSO algorithm in this application is compared with those of the GA. The transient response analysis is used for these comparisons. At the end of the analysis, the maximum overshoots and the settling times of the control system which is optimized with PSO algorithm are smaller than the results of GA algorithm. The results obtained in this paper may be improved the control systems that depend on PID by using GPID.

Table(2) GPID, PID Parameters after Tuning by PSO

Objective Function	Tuned GPID parameters				Tuned PID Parameters		
	K_p	K_i	k_d	k_a	K_p	K_i	k_d
ISE	0.4203	0.0003	16.2854	0.0001	0.0667	0.00002	14.1347
ITAE	0.0565	0.001	5.9621	8.6308	0.0402	0.0002	4.5668
IAE	0.0565	0.0002	5.9621	8.6308	0.0589	0.0001	7.6026

Table(3) GPID, PID Response Specifications after Tuning by PSO

Objective Function	*GPID Response*			*PID Response*		
	RiseTime	*SettlingTime*	*Overshoot*	*RiseTime*	*SettlingTime*	*Overshoot*
ISE	*0.0256*	*0.0557*	*7.1100e-006*	*0.1497*	*0.2212*	*0.8566*
ITAE	*0.1741*	*0.2821*	*0.0218*	*0.2299*	*0.3660*	*0.2328*
IAE	*0.1602*	*0.2337*	*1.6574*	*0.1568*	*0.2276*	*1.6425*

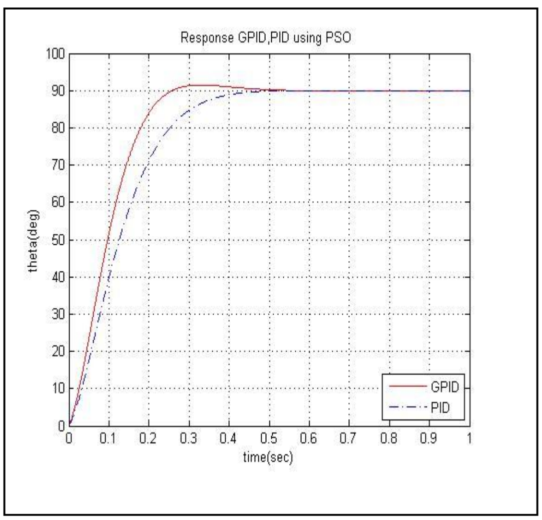

Figure (3) Response based on ISE

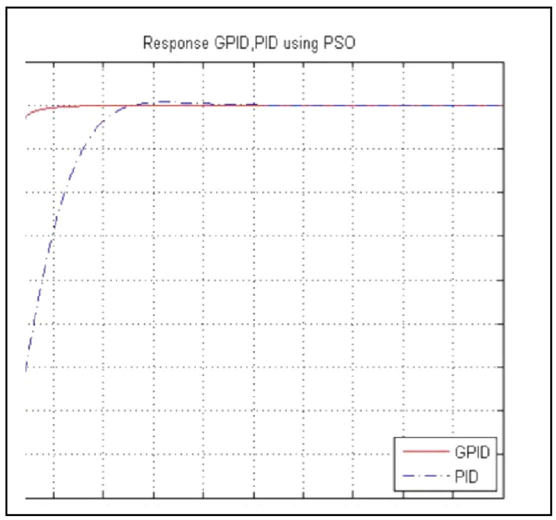

Figure (4) Response based on ITAE

Table(4) Comparison between PSO and GA

Tuning Method	*Overshoot*	*Settling Time*	*Rise Time*
PSO	0.0032	0.0681	0.0143
GA	12.040503	0.1091	0.0298

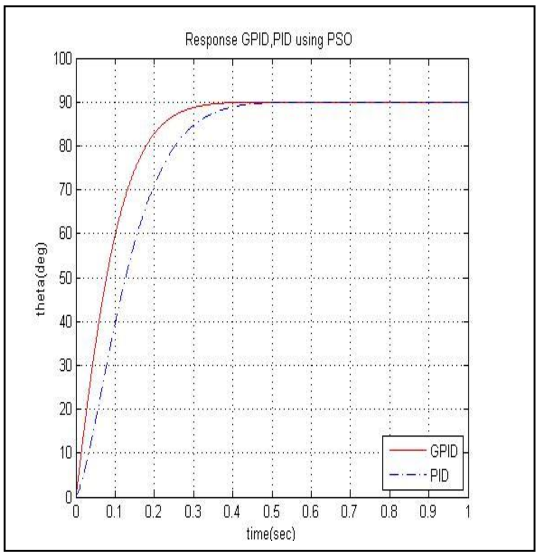

Figure (5) Response based on IAE

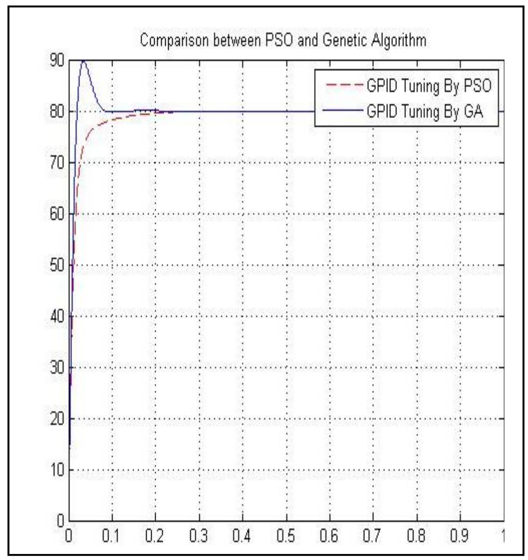

Figure (6) Comparison between PSO and GA

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