Design of an Auto-Tuning PID Controller for Systems based on Slice Genetic Algorithm

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Abstract – This paper introduces the Slice Genetics Algorithm SGA which represents the proposed modification to the classic Genetic Algorithm GA scheme. The proposed algorithm has reduced the population size and maximum iteration in order to get fast and an optimal solution. This algorithm has been used for determining the optimal proportional- integral- derivative PID controller parameters. The proposed algorithm has versatile features, including, fast, stable rate convergence characteristic also it has good computational efficiency in improving the dynamic behavior for the system in term of reducing the maximum overshoot, rise time, settling time and steady-states error. The algorithm not only has benefit to improve the convergence characteristic, accuracy but it also shortened the processing time towards the optimal value based reducing the number of iteration from 40 to 4 or 6 iteration as clear in the MATLAB simulation results..

Keywords – PID Controller; Slice Genetic algorithm.

1. Introduction

In the recent years, PID controller has been used widely for processes and motion control systems in industry. Now more than 90% control systems is still PID controller. The most critical step in application of PID controller is parameters tuning. Today self-tuning PID digital controller provides much convenience in engineering [1, 2]. The most critical step in application of PID controller is parameters tuning. Today self-tuning PID controller provides much convenience in engineering. One of the well-known optimization algorithms that are used for tuning the PID parameters is GA. The basic principles of GA were first proposed by Holland 1970s [3]. This technique was inspired by the mechanism of natural selection, a biological process in which stronger individual is likely to be the winners in a competing environment. GA uses a direct analogy of such natural evolution to do global optimization in order to solve highly complex problems [4] .GAs is used regularly to solve difficult search, optimization, and machine-learning problems that have previously resisted automated solutions. They can be used to solve difficult problems quickly and reliably. These algorithms are easy to interface with existing simulations and models, and they are easy to hybridize. GAs includes three major operators: selection, crossover, and mutation, in addition to four control parameters: population size, selection pressure, crossover and mutation rate [5]. Recent search has identified some deficiencies in GA performance. This degradation in efficiency is apparent in applications with highly *epistatic* objective functions (i.e., where the parameters being optimized are highly correlated), the crossover and mutation operations cannot ensure better fitness of offspring because chromosomes in the population have similar structure and their average fitness are high toward the end of the evolutionary process [6].

The fundamental essence of the contribution of this work is to modify and improve the genetic algorithm through the proposed slice genetic algorithm that has a novel modified with high efficiency algorithm in terms of finding the optimal parameters for the PID controller and reducing the number of function evaluation through minimizing the population size and the number of iteration. Therefore this proposed algorithm will improve the convergence characteristic, accuracy, reduce the processing time and improve the step response characteristic for the system such as, reducing the maximum overshoot, rise time, settling time and steady-states error.

The remainder of this paper is organized as follows:

Section two, the PID controller model and GA are reviewed. Section three introduced the proposed slice genetic algorithm learning. In section four, simulation results of the proposed auto-tune PID controller based on slice genetic algorithm are presented and compared with other methods and the conclusions are drawn in section five.

2. PID Controller Model

The PID controller is well known and widely used to improve the dynamic response as well as to reduce or eliminate the steady state error. The derivative controller adds a finite zero to the open loop system transfer function and improves the transient response. The integral controller adds a pole at the origin, thus increasing system type by one and reducing the steady state error due to a step function to zero [7]. It is assumed that the ideal transfer function of a PID controller is given in the s-domain as follows:

$$Gc(s) = P + I + D = K_p + \frac{K_i}{s} + K_d s \qquad (1)$$

Where: K_p, K_i and K_d are the PID controller gains.

The PID controller controls the electrode feed-rate, based on the feedback signal obtained from the current sensor .But in the actual production, PID parameters setting is difficult, the parameters setting of the conventional PID controller is often not good and the performance is poor. During the past decades, great attention has been paid to optimization methods for controller and people have been looking for the automatic setting technology for PID controller parameters. For example: Ziegler-Nichols method, indirect optimization method, the gradient method and climb method. These methods have good optimization features which can make the system performance improved. But in the control process, there are some drawbacks such as sensitive to the initial value and easy to fall into local optimal solution also they can't succeed to find the optimal solution.

In fact, the actual industrial production processes are nonlinear and time-varying systems. Application of conventional optimization method is difficult to establish accurate mathematical model, the controller can't achieve ideal control effect [8].

3. The Proposed Slice Genetic Learning Algorithm

Genetic algorithm is an intelligent optimization technique that relies on the parallelism found in nature; in particular its searching procedures are based on the mechanics of natural selection and genetics. GAs includes three major operators: selection, crossover, and mutation, in addition to four control parameters: population size, selection pressure, mutation rate and crossover [9]. GA has the ability to solve difficult, multi dimensional problems with little problem-specific information and hence has been chosen as the optimization technique to solve various problems in control systems. It has been shown that compared with other traditional heuristic optimization method, Genetic Algorithm is likely to be more computationally efficient. The controller parameters are usually determined by trial-and-error through simulation. In such case, the paradigm of GA appear to offer an effective way for automatically and efficient searching for a set of control performance [10].

The steps of the tuning the parameters of the PID controller using genetic algorithm can be described as follows:

Step1: GA makes the problem parameters into chromosomes then simulates evolutionary operation.

Step2: To determine the size of the population and to initialize. Set the population size 30, the evolution generation 100.

Step3: Decode the individual of the population into optimal parameters for calculating the value of fitness function and evaluating.

Step4: Do population selection, crossover and mutation operations to produce the next generation population. The crossover probability is 0.6, mutation probability is 0.01.

Step5: Repeat steps 3 and 4 until the parameters of the fitness function satisfy the condition [8].

The design of a control system is an attempt to meet a set of specifications which define the overall performance of the system in terms of certain measurable quantities. In the normal way design of control system, some specific parametric values of the system are assumed and the control system is designed accordingly to meet desired performance of the system.

It can be used three most commonly mathematical functions as a performance index associated with error of a closed loop system [10].

$$IAE = \int_0^\infty abs(e(t))dt \qquad (2)$$

$$ISE = \int_0^\infty e^2(t)dt \qquad (3)$$

$$ISTE = \int_0^\infty te^2(t))dt \qquad (4)$$

The time domain criterion is used for evaluating the PID controller and a set of a good control parameters *P*, *I* and *D* can yield a good step response that will result in performance criteria minimization in the time domain. These performance criteria in the time domain include the overshoot, rise time, settling time, and steady-state error. Therefore, the performance criterion is defined as follows [6].

$$f = \min((1-e^{-B})(Mp + e_{ss}) \times e^{-B}(t_s - t_r)) \qquad (5)$$

Where,
B: Tuning factor.
M_p: Maximum overshoot.
e_{ss}: Steady state error.
t_s: Settling Time.
t_r: Rise time.

The structure of the proposed algorithm for tuning the parameters of the PID controller based on slice genetic can be shown in Figure (1).

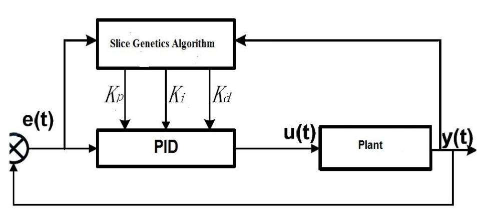

Fig. (1): The Proposed structure of the tuning PID controller based slice genetic algorithm.

In this paper, it is proposed new performance criterion, as shown in equation (6) ; this proposed algorithm will improve the convergence characteristic, accuracy, reduce the processing time and improve the step response characteristic for the system such as, reducing the maximum overshoot, rise time, settling time and steady-states error.

$$F = Max(-K \times ((B \times (M_p + E)) + ((1-B) \times (T_s - T_r))) \qquad (6)$$

where:
B: Tuning factor 0 < B < 1
K: scaling factor K >1
M_p: Maximum overshoots
E: median (1-y)
y: Output
T_s: Settling Time
T_r: Rise time.

The steps of the tuning the parameters of the PID controller using slice genetic algorithm can be described as follows:

1. Create n slice random initial population see Figure 2.
2. Calculate the fitness for each individual in each slice
3. For each slice Vertically find global maximum fitness
4. Horizontally find the slices global maximum fitness.
5. Check Objective
6. Duplicate the individual horizontally which sponsor with horizontal maximum fitness
7. Make selection
8. Apply arithmetic random crossover.(this will let the duplicated individuals produced their best
9. Apply mutation.
10. Calculate the fitness to the Vertically find the slices global maximum fitness
11. Horizontally find the slice global maximum fitness “i.e. maximum fitness in the same position”

12. Find the optimal global by comparing step 8 to step 4.
13. Compare and replace the fitness of the current generation with the previous one to create the new population.
14. Steps 6 to 12 are repeated until stopping criterion is satisfied**.**

The flowchart for the proposed slice genetic algorithm can be described in Figure (3).

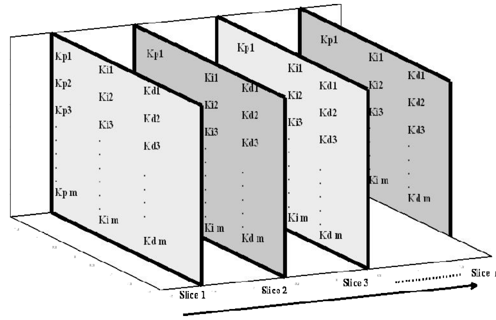

Fig. (2): The Slice genetic population

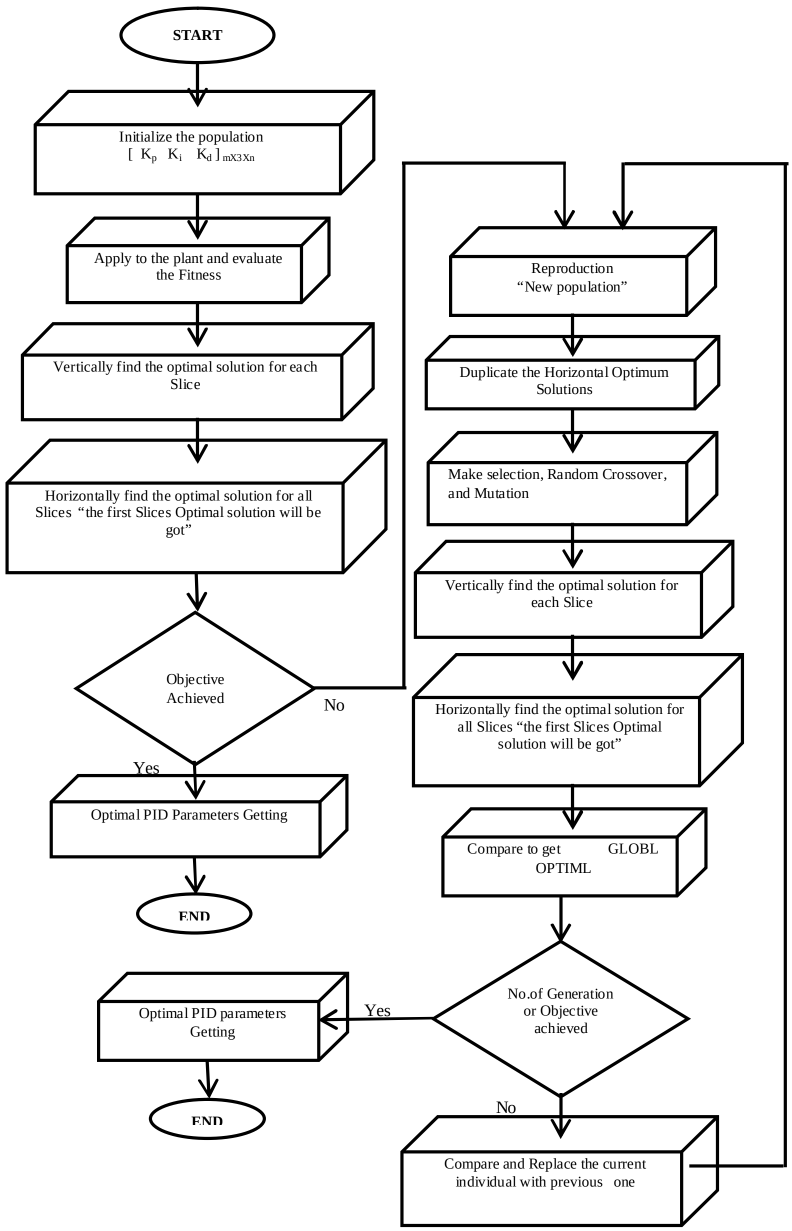

Fig. (3): The proposed slice genetic algorithm flow diagram

The fundamental essence of the proposed slice genetic algorithm is dividing the population into slices leads to implement the optimization in multi dimensions in order to speed up and to get the close optimal solution. Also the duplication of the good individuals and the applying random crossover on it will give high opportunity to show all the good traits comparing the present solution with the previous one cause best improvement to the overall solution.

This proposed algorithm has reduced the number of iteration where increasing the number of iteration will lead the genetic algorithm to saturate on the closest near optimal solution.

4. Simulation Results

The proposed auto tuning PID controller based on slice genetic algorithm is verified by means of computer simulation using Matlab package.

System I

The first plant has been taken from [7] which can be expressed as follows transfer function:

$$G(s) = \frac{400}{S(S^2 + 30S + 200)} \qquad (7)$$

After applying the slice genetic algorithm for tuning the parameters of the PID controller in order to find sets of optimal response in terms of minimum population size and the number of iterations as well as the best response depends on the dynamic behavior of the system such as rising time, settling time, overshoots and steady state error, as shown in Figure (4) and Table (1).

Table (1): Sets of the PID controller parameters with different output response.

Gen.No.	Kp	Ki	Kd	Tr	Ts	Mp %	Ess
#1	2.8393	0.2801	0.0481	0.248	0.901	15.5	0
#2	1.7999	0.5265	0.1526	0.423	5.234	6.3	0
#3	4.0859	0.3991	0.5425	0.178	0.338	1.04	0
#4	4.0859	0.3991	0.5425	0.178	0.338	1.04	0

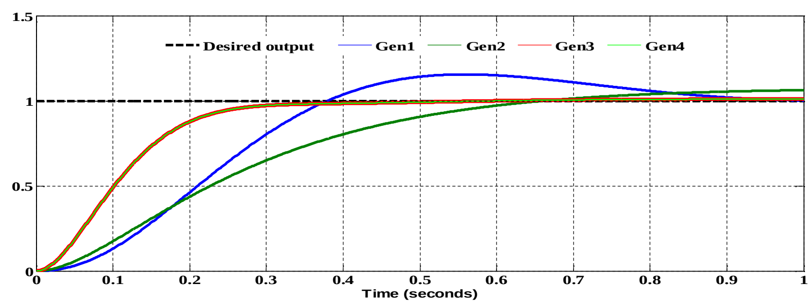

Fig. (4): The response of the system for four cases

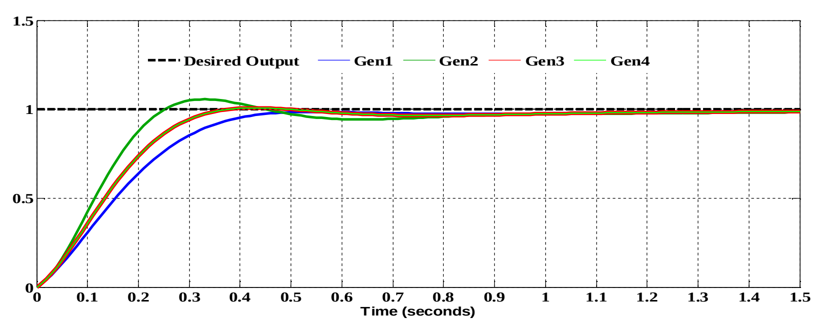

Fig. (5): The response of the system for four cases

To investigate the high performance of the proposed controller algorithm; the simulation results of the PID controller has compared with an adaptive GA based self tuning PID controller results that has been taken from [7] as shown in Table 2.

Table (2): Output response of the system with different control algorithms

Parameters of Algorithm	Proposed Algorithm	Algorithm in [7]
Population size	6 in 3 slice=18	50
Crossover rate	0.7	0.6
Mutation rate	0.06	0.06
Number of iterations	4	100
P-gain	4.0859	9.43
I-gain	0.3991	0.81
D-gain	0.5425	0.22
Tr (s)	0.178	0.28
Ts (s)	0.338	0.75
Mp%	1.04	6
Ess	0	0

System II

The second system has been taken from [11] that it is the armature-controlled dc motor which can be expressed as follows transfer function:

$$G(s) = \frac{1}{10^{-5} S^3 + 0.04534 S^2 + 0.5524 S + 1} \quad (8)$$

Then applying the proposed algorithm for tuning the parameters of the PID controller and find sets of optimal response for the system in terms of minimum population size and the number of iterations as well as the best response depends on the dynamic behavior of the system, as shown in Figure (5) and Table (3).

Table (3): Sets of the PID controller parameters with different output response

Gen.No.	Kp	Ki	Kd	Tr	Ts	Mp%	Ess
#1	3.1378	5.0131	0.0797	0.295	1.110	0	0
#2	5.3189	6.3137	0.0568	0.171	1.33	5.64	0
#3	3.9377	5.7500	0.0802	0.232	1.121	0	0
#4	3.9377	5.7500	0.0802	0.232	1.121	0	0

The simulation results of the proposed PID control methodology based on slice genetic algorithm has compared with the results of the current search (CS) met-heuristics that has been taken from [11], as shown in Table 4.

Table (4): Output response of the system with different control algorithms

Parameters of Algorithm	Proposed Algorithm	Algorithm in [11]
No of solutions	4 in 2 slice =8	10
Number of runs	4	20
P-gain	3.9377	1.6501
I-gain	5.7500	4.0986
D-gain	0.0802	0.0049
Tr (s)	0.232	0.8506
Ts (s)	1.121	2.0104
Mp%	0%	4.04%
Ess	0	0.3

System III

The third plant has been taken from [8] which can be described by the following transfer function:

$$G(s) = \frac{2e^{-0.2S}}{S^2 + 1.5S + 2} \quad (9)$$

It is used the proposed algorithm for tuning the parameters of the PID controller and to find sets of optimal response for the system to get the best dynamic behavior response, as shown in Figure (6) and Table (5).

Table (5): Sets of the PID controller parameters with different output response.

Gen. No.	Kp	Ki	Kd	Tr	Ts	Mp%	Ess
#1	4.9437	56.7635	29.0844	0.0408	0.3090	0	0
#2	4.4687	56.1941	29.6266	0.0400	0.3320	0	0
#3	2.1579	39.4576	47.1942	0.0245	0.0564	0	0
#4	7.6060	24.3814	82.1394	0.0137	0.0270	0	0
#5	7.6060	24.3814	82.1394	0.0137	0.0270	0	0

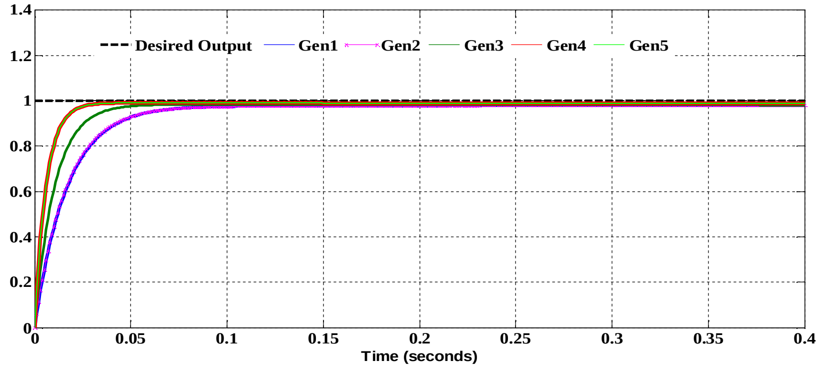

Fig. (6): The response of the system for five cases

To validate the high performance of the proposed controller algorithm; the simulation results of the PID controller has compared with another results that has been taken from [8], as shown in Table (6).

Table (6): Output response of the system with different control algorithms

Parameters of Algorithm	Proposed Algorithm	Algorithm in [8]
Population size	4 in 3 slice=12	30
Crossover rate	0.75	adaptive
Mutation rate	0.06	adaptive
Number of iterations	5	57
P-gain	7.6060	2.0534
I-gain	24.3814	1.4338
D-gain	82.1394	2.3251

5. Conclusion

The slice genetic algorithm for tuning the parameters of the PID controller has been presented in this paper. The novel of the proposed algorithm has modified, improved and increased the efficiency of the genetic algorithm through reducing the number of function evaluation and minimizing the population size and the number of iteration. Simulation results of tuning the parameters of the PID controller for the different systems show that the effectiveness of proposed tuning slices genetic algorithm to find the best values of the parameters of the PID controller; this is demonstrated by the minimized the dynamic behavior of the system response such as the overshoot, rise time, settling time and steady-states error. Also this proposed algorithm has improved the convergence characteristic, accuracy and reduced the processing time in comparing with other methods.

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