

A Study for Learning Method of Modified PID Controller with On-line Hybrid Genetic Algorithm

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Abstract. The PID control system is one of the most famous controllers in the industrial products because it doesn't need theoretical knowledge to adjust unknown variable in the controller. In former study, a GA (genetic algorithm) was used to tune the parameters of PID. These studies attempt to find PID one and their results is pretty good. But these trials work on off line because it still needs too much calculating time.

This study is concerned about learning method of on-line GA. At the first, the limitations of variables of PID are selected by relay feedback. At the second, the time range for object function also has limited by the time constant in the Ziegler-Nichols Method. At the final, parameters of PID are optimized by on-line GA that is hybrid GA based on micro GA.

Keywords: Machine learning · Micro GA · On-line GA · PID tuning

1 Introduction

Machine learning consists of representation, evaluation and optimization. All systems have been represented computer's language to handle in machine learning. These systems have to optimize automatically on evaluation function [1]. In this light, a PID control system is great application for machine learning. A PID control system is driven by computer and it has cost function that is composed of rapid response, robust, error and so on. This control system also needs to find suitable variables on cost function.

There are few researches to find parameters of PID controller. A step response shape or vibration period when system was critical stable state are used to find PID's variables [2]. Or relay response also is used for PID's variables optimization [3]. GA also was used to adjust controller's parameters [4]. These studies are tuning methods to adjust unknown parameters because they are calculated in off-line condition.

To apply the machine learning algorithm to a PID control system, every optimization process can be programmed in a computer. This paper uses the hybrid GA to minimize object function on PID controller. This HGA is some kind of micro GA. Micro GA is a binary coded GA that can drive with small amount of program. So this GA has an advantage on running speed. And relay feedback method is applied to limit

the solution domain. Usually population is generated randomly in the GA. When population is initialized, it is controlled by Ziegler Nichols method to increase the program's speed. A range of fitness calculation also is limited by time constant on step response. Each process is confirmed by off-line example.

2 Learning of PID Controller

2.1 Controlled System

A Fig. 1 is a travel motor system. A travel motor is consisted of planetary gear and swash type hydraulic motor. This hydraulic motor has regulator that controlled motor's speed with changing of swash angle. And regulator is connected with cylinder of EHA (electro-hydrostatic actuator). If EHA's cylinder was controlled by electric motor, travel motor's speed will be changed. A Fig. 2 is a hydraulic circuit of test bench. A displacement of EHA's cylinder is sensed by LVDT (linear variable differential transformer) and this cylinder was driven by electric motor. Test bench has load cylinder to simulate regulator's load.

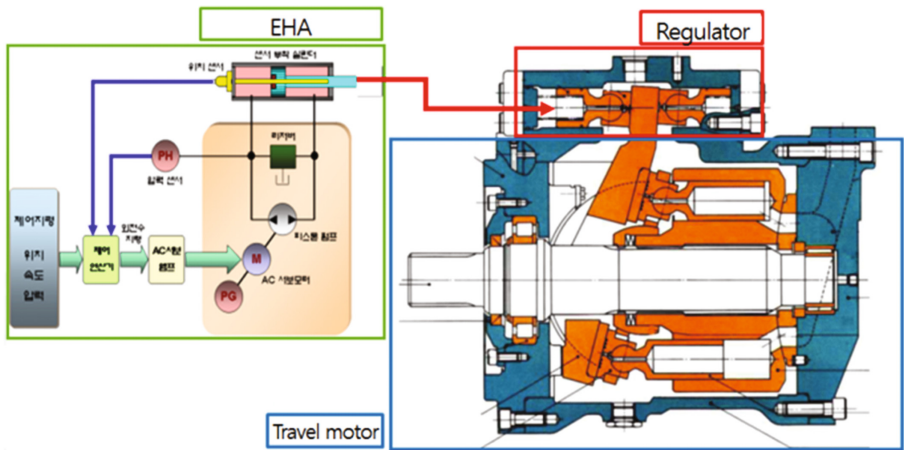


Fig. 1. A suggested travel motor system

This system that assume the travel motor was identified as follow

$$G(s) = e^{-0.31916t} \frac{3.0107}{s + 0.0514} \tag{1}$$

2.2 Limitation of PID Parameter's Solution Domain

It is important to limit the parameter's solution domain in on-line GA. A variable's searching area has been limited to reduce the learning phase for total system. If searching area has increased, learning phase is getting longer. And every variable has to

Circuit

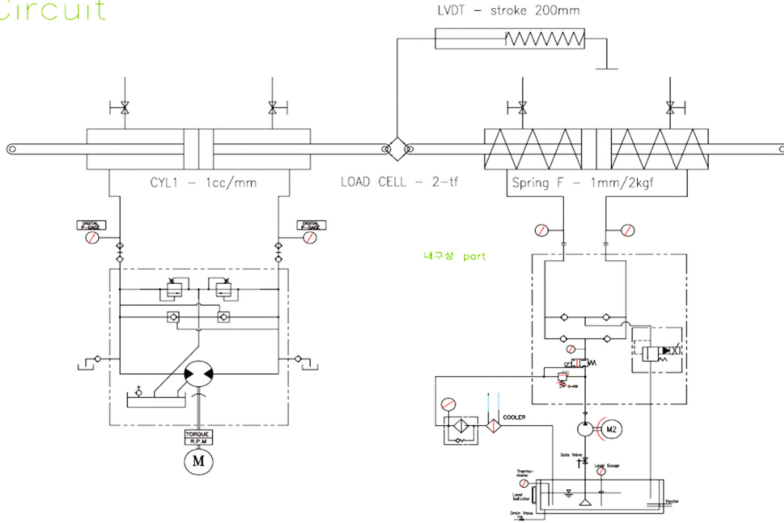


Fig. 2. Hydraulic circuit of test bench

locate in stable area to protect from damages. When controller has unstable parameter, the on line controlled system will be damaged. Usually GA initializes the first population randomly. This random chromosome will damage the controlled system when use the on-line GA.

This study uses a relay feedback method to find Ziegler-Nichols method. Park was used Ziegler-Nichols method to reduce the solution domain on PID controller with RCGA (real coded genetic algorithm) [5]. If Ziegler-Nichols method can be used on-line, it can reduce the solution domain effectively. And that answer is a relay feedback method.

Figure 3 is a Simulink program for relay feedback. And Fig. 4 is a result from Simulink program.

Table 1 is variables of normal Ziegler-Nichols method when PID controller looks like Eq. (2) [6].

$$C(s) = K \left(1 + \frac{1}{T_i s} + T_d s \right) \tag{2}$$

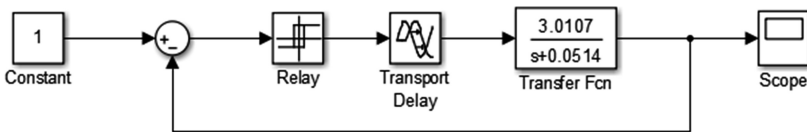


Fig. 3. Simulink program for relay response

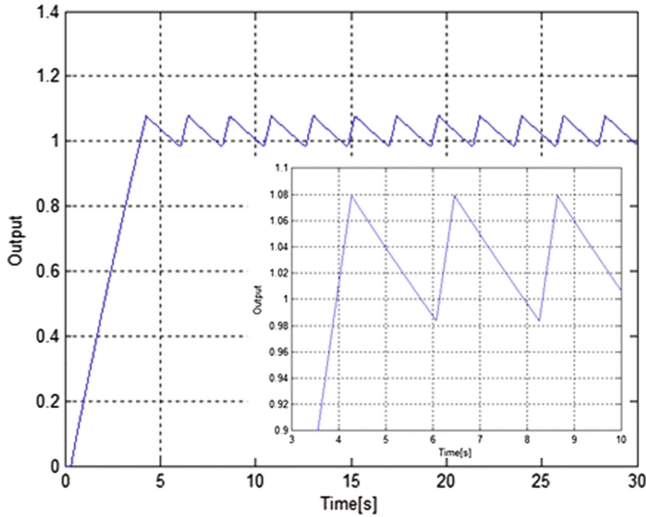


Fig. 4. Result of relay response

Table 1. Variables of normal Ziegler-Nichols method

Variable	K	T_i	T_d
P	$0.5K_u$	–	–
PI	$0.4K_u$	$0.8T_u$	–
PID	$0.6K_u$	$0.5T_u$	$0.125T_u$

where, K is gain. T_i is integral time and T_d is derivative time.

Where, K_u is as follow [5].

$$K_u = \frac{4d}{\pi a} \tag{3}$$

where, a is an amplitude of system’s output and d is an amplitude of relay input. d is 1 and epsilon of relay function is 0.0001. a is 0.095 from Fig. 4, and K_u is 1.3403. T_u is cycle time of system’s output. T_u is 2.187 from Fig. 4.

Figure 5 is shown a step response at normal Ziegler-Nichols method.

Table 2 is variables of modified Ziegler-Nichols method. This method can be supported more smoothed step response than original [3]. A Fig. 6 is a step response at modified Ziegler-Nichols method.

A system’s characteristic equation is as follow when system’s block diagram is Fig. 7.

$$T_i(KT_d + \tau)s^2 + T_i(K + 1)s + K = 0 \tag{4}$$

Table 2. Variables of modified Ziegler-Nichols method

PID type	K	T_i	T_d
Original	$0.6K_u$	$0.5T_u$	$0.125T_u$
Little overshoot	$0.33K_u$	$0.5T_u$	$T_u/3$
No overshoot	$0.2K_u$	$0.5T_u$	$T_u/3$

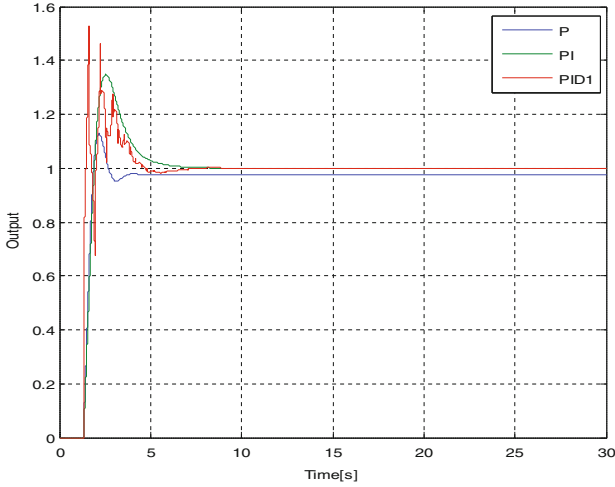


Fig. 5. Step response at normal Ziegler-Nichols method

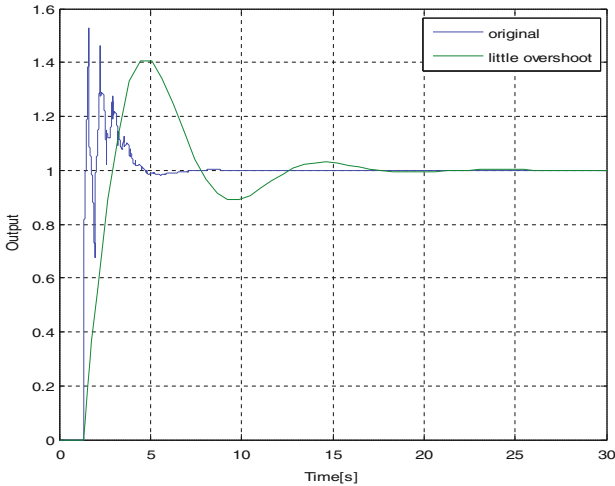


Fig. 6. Step response at modified Ziegler-Nichols method (original VS. little overshoot)

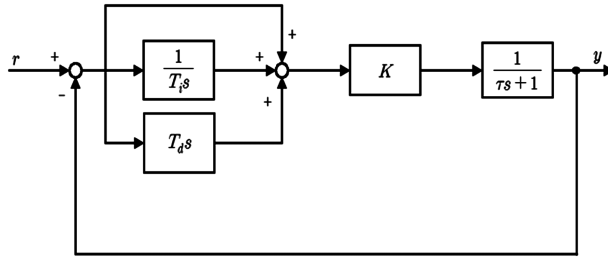


Fig. 7. Block diagram for 1 order system with PID controller

Each variable has to satisfy Eq. (5) to stable from the Routh stability criterion.

$$K > 0, T_i > 0, T_d > -\frac{\tau}{K} \tag{5}$$

Therefore each variable is bigger than 0 and smaller than twice of modified Ziegler-Nichols method’s parameter.

2.3 Limitation of Time Range for Object Function

Learning time for on-line GA is proportional to time of object function’s calculation. Because an object function is generate from step response error on each chromosome. Each generation needs to calculate the fitness function for chromosome. If on-line GA has 100 generation, 20 chromosomes with 30 s step response, learning time of this system is almost 60,000 s. It is important to select time for object function.

A 5% settling time is about 3T (time constant) on 2 order system. A 2% settling time is about 4T at same condition. So in this study, limitation of time range is 5T in step response when PID’s parameters replace on little overshoot type.

2.4 Modified PID Controller

The original PID controller has a pure derivative. This derivative part will give a very large amplification of measurement noise. When measurement noise is amplified, system’s error is chattered. Therefore controlled system is getting unstable. By this reason, this study use modified PID controller as follow [7].

$$u(t) = K(b(r(t) - y(t)) + \frac{K}{T_i s}(r(t) - y(t)) - \frac{KT_d s}{1 + \frac{T_d}{N} s}y(t) \tag{6}$$

where, *b* is acted on proportional term and a *N* is adjusted low-pass filter. *b* is limited from 1 to 10 in the hybrid GA. And *N* is limited from 1 to 20 at same condition.

2.5 Simulation with Hybrid GA

A micro GA is one of the BCGA (binary coded genetic algorithm). It has 5 populations and simple structure. This micro GA’s calculation’s running time is faster than real coded GA. So it was used for structural optimization [8]. Pham and Jin had suggested hybrid GA that based on micro GA. This hybrid GA is non-sensitive on strong chromosome in initial generation [9]. This study uses this hybrid GA.

Initial population is generated randomly. Each chromosome (variable) is limited on solution area. And each chromosome’s fitness was calculated by fitness function (object function). A reproduction operator is selected optimal chromosome that based on fitness value. A crossover operator is evolved the reproduced population. A mutation operator is scanned the unexpected solution area. If generation is increased, population is evolved by genetic operator and population’s chromosome goes to optimal value. A Table 3 is GA’s parameters for hybrid GA. And a Table 4 is results of hybrid GA when generation was changed. A Fig. 8 is shown that results of simulation are not quite different when its generation was 100 and 10000.

Table 3. GA’s parameters for hybrid GA

Parameter		Value
Generation		100
Population		6
Operator	Reproduction	Gradian-like selection
	Crossover	One-pointcrossover (crossover probability = 1.0)
	Mutation	simple mutation (mutation probability = 0.008)
Strategy		Scaling window(ws = 1) Elitism

Table 4. Results if hybrid GA

Generation	b	N	K	T_i	T_d	Obj. Func.
10	2.5409	7.9752	0.3923	0.3493	0.4300	16454.296
20	2.5499	7.7653	0.3926	0.3472	0.4302	16383.297
50	2.5513	7.5615	0.3927	0.3348	0.4043	16368.675
100	2.5590	7.2417	0.3916	0.3515	0.5370	16363.749
200	2.5597	7.2707	0.3916	0.3556	0.4281	16359.149
300	2.5597	7.2788	0.3916	0.3554	0.4365	16359.016
500	2.5597	7.2785	0.3916	0.3554	0.4363	16359.008
1000	2.5597	7.2785	0.3916	0.3554	0.4359	16359.007
10000	2.5597	7.2785	0.3916	0.3554	0.4360	16359.006

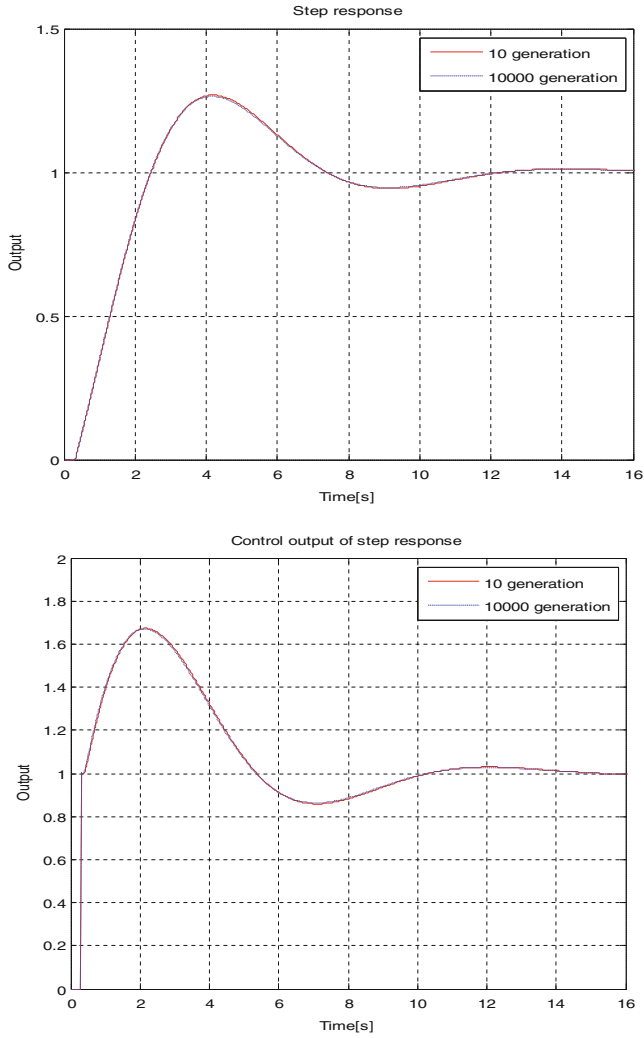


Fig. 8. Step responses and its control outputs (generation 100 vs. 10000)

Table 5. Results if hybrid GA when a rate of generation and population was changed

Gen.	Pop.	b	N	K	T_i	T_d	Obj. Func.
100	6	2.5590	7.2414	0.3916	0.3515	0.5370	16363.749
50	12	1.6527	16.3722	0.6319	1.2364	0.3968	16308.333
25	24	3.4419	6.9274	0.2943	0.7758	0.4903	16236.293
20	30	2.6465	3.8595	0.3824	1.6192	0.7410	16258.969
10	60	9.9511	6.2499	0.0992	0.2820	0.0336	15996.037

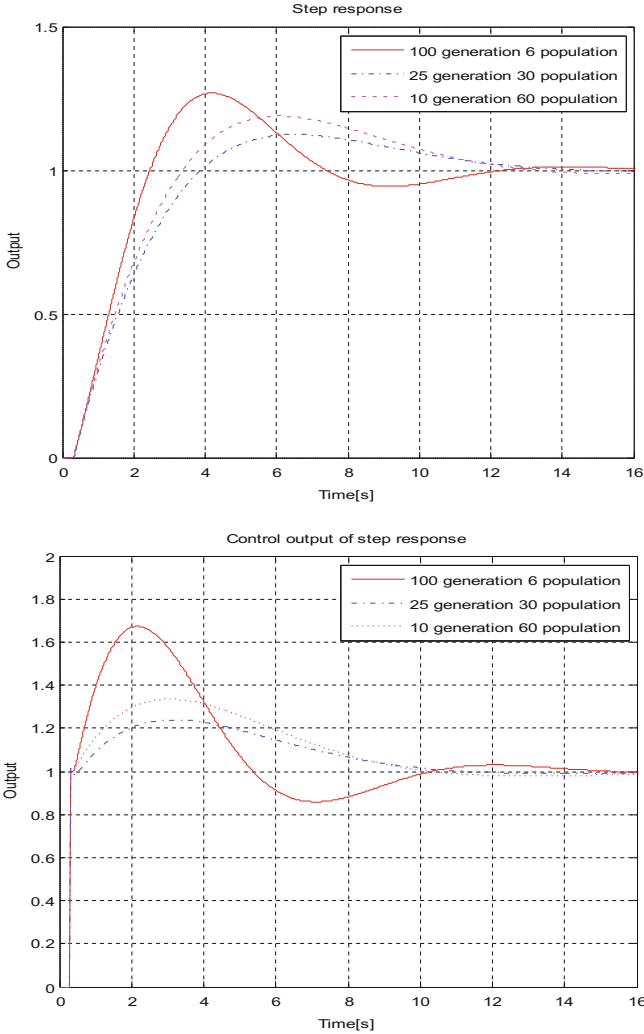


Fig. 9. Step responses and its control outputs when a rate of generation and population was changed

Table 5 is results of hybrid GA's simulation when number of object function's calculation was fixed as 6000 times. A Fig. 9 is shown that results of simulation when the rate of generation and population was changed. If GA has been increased population, the result has been improved. But this study's purpose is find the GA algorithm for machine learning and a microprocessor has limited on the memories. So the rate of generation and population was selected nearby a 1:1 in this study.

3 Conclusion

Machine learning is a program that can optimize the control system from outer data without operator's judgments. To apply the machine learning into the GA, it needs some techniques. This study uses the relay feedback method to generate GA population and make a fitness calculation window to reduce a learning phase. In the next study, a structure of hybrid GA was changed as a parallel GA to use the dual core DSP (digital signal processor, Delfino™ F28377D, Texas instrument).

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