Tuning Algorithms for PID Controller Using Soft Computing Techniques

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Summary
PID controllers are widely used in industrial plants because it is simple and robust. Industrial processes are subjected to variation in parameters and parameter perturbations, which when significant makes the system unstable. So the control engineers are on look for automatic tuning procedures. In this paper, the parameters of PID controller are tuned for controlling the armature controlled DC motor. Continuous cycling method & Z-N step response method are the conventional methods whose performance have been compared and analyzed with the intelligent tuning techniques like Genetic algorithm, Evolutionary programming and particle swarm optimization. GA, EP and PSO based tuning methods have proved their excellence in giving better results by improving the steady state characteristics and performance indices.

Key words: Genetic algorithm, Evolutionary programming and particle swarm optimization

1. Introduction

The general equation of PID controller is

$$U(t) = K_p\, e(t) + 1/Ti\int e(t)dt + Td \times de(t)/dt + P_0$$

Where,

K_p = proportional gain

T_i = integral time

T_d= derivative time

The variable e(t) represents the tracking error which is the difference between the desired input value and the actual output. This error signal will be sent to the PID controller and the controller computes both the derivative and the integral of this error signal.

The signal U(t) from the controller is now equal to the proportional gain (K_p) times the magnitude of the error plus the integral gain (K_i) times the integral of the error plus the derivative gain (K_d) times the derivative of the error [2].

2. Need for controller tuning:

The control system performs poor in characteristics and even it becomes unstable, if improper values of the controller tuning constants are used. So it becomes necessary to tune the controller parameters to achieve good control performance with the proper choice of tuning constants [7].

2.1. Methods for PID Controller Tuning

The PID control algorithm is used for the control of almost all loops in the process industries, and is also the basis for many advanced control algorithms and strategies.

In order to use a controller, it must first be tuned to the system. This tuning synchronizes the controller with the controlled variable, thus allowing the process to be kept at its desired operating condition. Standard methods for tuning controllers and criteria for judging the loop tuning have been used for many years. Some of them are Mathematical criteria, Cohen- coon Method, Trial and error method, Continuous cycling method, Relay feed back method and Kappa-Tau tuning method. From the above mentioned methods, four have been selected, tuned, designed and the results obtained were compared. These results thus show a better method to be opted [3].

3. Reason for Selecting Soft Computing Techniques

1. Model type: Many methods can be used only when the process model is of a certain type, for example a first order plus dead time model (FOPDT). Model reduction is necessary if the original model is too complicated.
2. Design criteria: These methods aim to optimize some design criteria that characterize the properties of the closed-loop system. Such criteria are, for example, gain and phase margins, closed-loop bandwidth, and different cost functions for step and load changes.
3. Approximations: Some approximations are often applied in order to keep the tuning rules simple.

The purpose of this project is to investigate an optimal controller design using the Evolutionary programming, Genetic algorithm, Particle swarm optimization techniques.

In this project, a new PID tuning algorithm is proposed by the EP, GA, and PSO techniques to improve the performance of the PID controller.

The ultimate gain and the ultimate period were determined from a simple continuous cycle experiment. The new tuning algorithm for the PID controller has the initial value of parameter Kp, T_i, T_d by the Ziegler-Nichols formula that used the ultimate gain and ultimate period from a continuous cycle experiment and we compute the error of plant response corresponding to the initial value of parameter.

The new proportional gain (K_p), the integral time (T_i), and derivative time (T_d) were determined from EP, GA, and PSO. This soft computing techniques for a PID controller considerably reduced the overshoot and rise time as compared to any other PID controller tuning algorithms, such as Ziegler-Nichols tuning method and continuous cycling method.

3.1 Genetic Algorithm

The steps involved in creating and implementing a genetic algorithm are as follows:

- Generate an initial, random population of individuals for a fixed size (according to conventional methods K_P, T_I, T_D ranges declared).
- Evaluate their fitness (to minimize integral square error).
- Select the fittest members of the population.
- Reproduce using a probabilistic method (e.g., roulette wheel).
- Implement crossover operation on the reproduced chromosomes (choosing probabilistically both the crossover site and the ‘mates’).
- Execute mutation operation with low probability.
- Repeat step 2 until a predefined convergence criterion is met.

3.2 Evolutionary Programming

There are two important ways in which EP differs from GAs.

First, there is no constraint on the representation. The typical GA approach involves encoding the problem solutions as a string of representative tokens, the genome. In EP, the representation follows from the problem. A neural network can be represented in the same manner as it is implemented, for example, because the mutation operation does not demand a linear encoding.

Second, the mutation operation simply changes aspects of the solution according to a statistical distribution which weights minor variations in the behavior of the offspring as highly probable and substantial variations as increasingly unlikely.

The steps involved in creating and implementing evolutionary programming are as follows:

- Generate an initial, random population of individuals for a fixed size (according to conventional methods Kp, Ti, Td ranges declared).
- Evaluate their fitness (to minimize integral square error).
- Select the fittest members of the population.
- Execute mutation operation with low probability.
- Select the best chromosome using competition and selection.
- If the termination criteria reached (fitness function) then the process ends.
- If the termination criteria not reached search for another best chromosome.

3.3 Particle Swarm Optimization

The PSO technique has reduced some disadvantage in previous evolutionary controller. The results of PSO technique is compared with classical method response result where we have seen great advancement of the response parameters.

Unlike the conventional techniques, wherein the particles having unfavorable costs are discarded and those with favorable costs are reproduced, the unification of particle clusters allows us to use the same position in the optimal solution space.

The *i* th particle other than the best one is made to assume different positions on the surface of the virtual sphere centered at the *i* th particle position, whose radius is the Euclidean distance between this and the best particle.

Every time, as the particles assume new positions, it is ensured to update the best particle by comparing the costs corresponding to these positions with the previously selected best particle cost.

Simultaneously, the best particle in a given instant is assumed to ‘diffuse attractant’ towards the rest of the particles in the cluster, which leads to establishment of ‘cones of attraction’ with axes connecting the best particle and the rest in the population. Subject to the condition that the angle subtended by the vector joining the *i* th particle to the best one and the vector joining the present and the next positions of the *i* th particle lies within q degrees.

4. Results and Discussions

The transfer function of the electric DC motor is in equation below [1]

$$\frac{\theta(s)}{V(s)} = \frac{K}{L_a J s^3 + (R_a J + B L_a) s^2 + (K^2 + R_a B) s}$$

L_a = armature Inductance
R_a = armature resistance
K = motor constant
J = moment of inertia
B = mechanical friction

The parameters of the electric DC motor have the following value respectively, J=0.042, B=0.01625, K=0.9, L=0.025, R=5 as a nominal value.

The transfer function of the electric DC motor is[1]

$$P(s) = \frac{0.9}{0.00105 s^3 + 0.2104 s^2 + 0.8913 s}$$

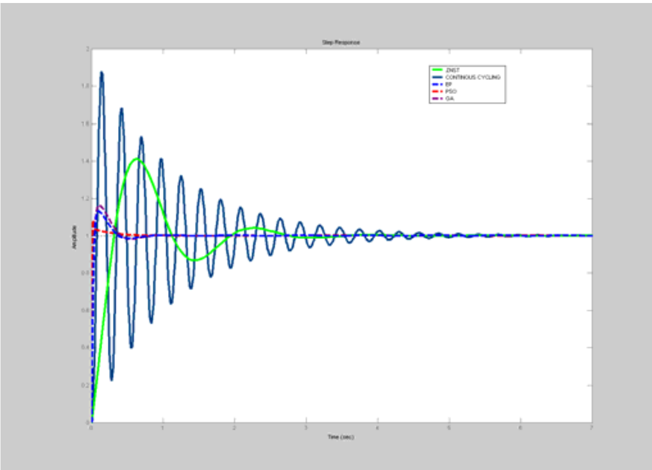

Figure1: Comparisons of All above Methods

All the conventional methods of controller tuning lead to a large settling time, overshoot, rise time and steady state error of the controlled system. Hence an Soft computing techniques is introduces into the control loop. GA, EP and PSO based tuning methods have proved their excellence in giving better results by improving the steady state characteristics and performance indices.

Performance Indices	Z-N (step response)	Kappa-Tau	Continuous cycling	EP	GA	PSO
ITAE	3.3805	3.3113	7.82	0.0721	0.3781	0.0229
IAE	0.5176	0.5188	0.56	0.4891	0.7712	0.9161
ISE	2.3467	2.2503	3.2	1.0277	1.0435	1.0016
MSE	0.0117	0.0112	0.016	0.0051	0.0052	0.0050

Table-1 Comparison of Performance Indices

Characteristics	ZNST	Continuous cycling	PSO	EP	GA
Peak over shoot (%)	41.4	87.6	8.81	13	12.9
Settling time (sec)	2.56	4.31	0.205	0.324	1.15
Rise time (sec)	0.242	0.0474	0.014	0.0317	0.0385

Table-2 Comparison of Steady State Responses

5. CONCLUSION

The GA, EP and PSO algorithm for PID controller tuning presented in this research offers several advantages. One can use a- high-order process model in the tuning, and the errors resulting from model reduction are avoided. It is possible to consider several design criteria in a balanced and unified way. Approximations that are typical to classical tuning rules are not needed. Soft computing techniques are often critized for two reasons: algorithms are computationally heavy and convergence to the optimal solution cannot be guaranteed. PID controller tuning is a small-scale problem and thus computational complexity is not really an issue here. It took only a couple of seconds to solve the problem. Compared to conventionally tuned system, GA, EP and PSO tuned system has good steady state response and performance indices.

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