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Francklin Rivas
University of the Andes (Venezuela)

Addison Rios
University of the Andes (Venezuela)

Neural Network-based Auto-Tuning for PID Controllers

FRANCKLIN RIVAS-ECHEVERRÍA*
ADDISON RÍOS-BOLÍVAR**
JEANETTE CASALES-ECHEVERRÍA
Universidad de Los Andes
Facultad de Ingeniería
Escuela de Ingeniería de Sistemas
Dpto. de Sistemas de Control
Mérida 5101
VENEZUELA

Abstract: - PID controllers have become the most popular control strategy in industrial processes due to the versatility and tunning capabilities. The incorporation of auto-tunning tools have increased the use of this kind of controllers. In this paper we propose a neural network-based self-tunning scheme for on-line updating of PID parameters, which is based on integral error criteria (IAE, ISE, ITAE, ITSE).

Keywords: - PID, Neural Networks (NN), Auto-tuning, Integral error criteria.

1 INTRODUCTION

Proportional-Integral-Derivative (PID) controllers are widely used in industrial processes, and can be implemented in different ways: as a stand-alone regulator or as a distributed component of a control system.

Systems with slow dynamics and few performance requirements, as most industrial processes, can be easily controlled using a PID strategy.

The incorporation of microprocessors in control systems has modified the meaning of controllers' operational characteristics as well as its algorithms. This fact has made possible self-diagnosis and auto-tuning.

PID controllers are often implemented with poor tuning, that deteriorates the system performance, in order to let the controlled system work under different conditions.

On the other hand, current microprocessors technology provides powerful computation capabilities, which may be used for tuning PID controllers.

The Ziegler and Nichols [19] methods are the most common PID tuning procedures. These methods are very simple and require few information of the system. Äström *et al* [1], Cohen *et al* [4] have presented the limitation of these methods. It also has been developed some alternative tuning procedures based on the Ziegler and Nichols methods [1,4, 7, 8, 11]

The first two objectives that need to be completed in an auto-tuning task are: Find a systematic, standard and automatic procedure for updating the controller parameters; and be sure that the system will reach the desired output in presence of process and industrial environmental changes.

Neural networks have been used in many industrial applications for control regulation [12], identification [13], pattern recognition [5], and fault detection [9, 17, 18]. Some of the reasons for using neural networks in those areas are:

- They can "learn" from historical patterns, i.e., so they may be use as associative memories.
- They present good generalisation results, i.e. it is possible to obtain appropriate outputs from patterns different to the used in the training stage.
- They can be used with incomplete or perturbed data, because the knowledge is distributed in the

interconnection weights of the network.

- They can build input-output maps from data without known relation.
- The computational implementation of Neural Network (NN) is easy.
- There exist many on-line and off-line learning algorithms, which can be adapted to a particular problem.

In this paper we propose a PID auto-tuning scheme using neural networks.

2 PID CONTROLLERS TUNING

The basic PID controller algorithm is as follows:

$$u(t) = K\left[e(t) + \frac{1}{T_i}\int e(t)dt + T_d \frac{de(t)}{dt}\right] \qquad (1)$$

where *u(t)* is the control signal, *e(t)* is the error between the reference signal *r(t)* and the system output *y(t)*. The controller parameters to be tuned are: the proportional gain *K*, the integral time T_i and the derivative time T_d.

Tuning is the process of finding the controller parameters according to the systems requirements. One of the methods used for PID controllers tuning consist in finding a model for the system and then calculate the controller parameters.

One of the Ziegler Nichols methods [19] consist in approximating the dynamical system using a first order model with time delay, as follows

$$G(s) = K_0 \frac{e^{-sT_m}}{ts+1} \qquad (2)$$

where K_0 is the dynamical system gain, *t* the time constant and T_m the time delay. Then, the PID controller parameters can be found.

In this paper we propose an optimal criteria-based PID tuning scheme, using the integral error. Considering that the error is the difference between the setpoint and the system output, this tuning procedure is implemented on-line in order to minimize the integral error.

Some tuning criteria [1, 14] used for minimizing the integral error, considering equations (1) and (2) are:

1.- Integral Absolute Error (IAE)

$$IAE = \int_0^\infty |e(t)|dt \qquad (3)$$

(a) PI Controller:

$$K = \frac{a_1}{K_0}\left(\frac{T_m}{t}\right)^{b_1} \qquad T_i = \frac{t}{a_2 + b_2(T_m/t)},$$

where

a_1=0.758
b_1=-0.916
a_2=1.02
b_2=-0.323.

(b) PID Controller:

$$K = \frac{a_1}{K_0}\left(\frac{T_m}{t}\right)^{b_1} \qquad T_i = \frac{t}{a_2 + b_2(T_m/t)},$$

$$T_d = a_3 t\left(\frac{T_m}{t}\right)^{b_3}$$

where

a_1=1.086
b_1=-0.869
a_2=0.740
b_2=-0.130
a_3=0.348
b_3=0.914

2.- Integral Time Absolute Error (ITAE)

$$ITAE = \int_0^\infty t|e(t)|dt \qquad (4)$$

(b) PI Controller:

$$K = \frac{a_1}{K_0}\left(\frac{T_m}{t}\right)^{b_1} \qquad T_i = \frac{t}{a_2 + b_2(T_m/t)},$$

where

a_1=0.586
b_1=-0.916
a_2=1.03
b_2=-0.165.

(b) PID Controller:

$$K=\frac{a_1}{K_0}\left(\frac{T_m}{t}\right)^{b_1} \qquad T_i=\frac{t}{a_2+b_2(T_m/t)},$$
$$T_d=a_3t\left(\frac{T_m}{t}\right)^{b_3}$$

where

a_1=0.965
b_1=-0.855
a_2=0.796
b_2=-0.147
a_3=0.308
b_3=0.9292

Similar expressions can be found in [14] for obtaining the controller parameters using other criteria as:

3.- Integral of Square Error (ISE)

$$ISE=\int_0^\infty e^2(t)dt \tag{5}$$

4.- Integral Time and Square Error (ITSE)

$$ITSE=\int_0^\infty te^2(t)dt \tag{6}$$

These tuning methods depend on setpoint changes or disturbance presence. In [10] can be found some formulas for PID controllers tuning according to Integral error criteria and based on a process model, as the one presented in (2). This method assumes that the systems respond the same to disturbance and to the control signals.

2.1.- PID Auto-tuning

PID controllers automatic tuning is carried out in two stages. First, the on-line parametric identification of the dynamic system and second, the computation of the appropriate PID controller parameters.

The auto-tuning method used in this paper deals with *parametric estimation* based on neural networks. This belongs to a class of adaptive controllers with two loops: The first one uses a recursive estimation algorithm in order to make a system parametric identification. The second loop updates the gains of the controller.

Figure 1 illustrates an auto-tuning scheme using parametric estimation.

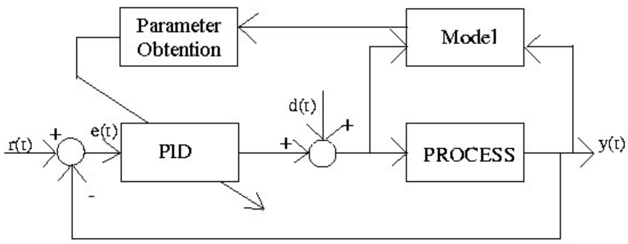

Figure 1. PID Auto tuning scheme using parametric estimation

3.- NEURAL NETWORKS-BASED PID CONTROLLER AUTO-TUNING

The auto-tuning scheme proposed in this paper, consist in a neural network-based on-line identification of the parameters K_0, t and T_m of the first order model with time delay, presented in equation (2). Then, using the tuning rules presented in the last section it is obtained the PID controller gains in order to minimize the integral error.

Figure 2 depicts the control loop containing the neural network used for updating the controller parameters. The neural network inputs are the setpoint, output and error signals of the system, and the outputs generated by the neural network are the parameters of the adjusted model of the system. These parameters are used for calculating the proportional, integral and derivative actions.

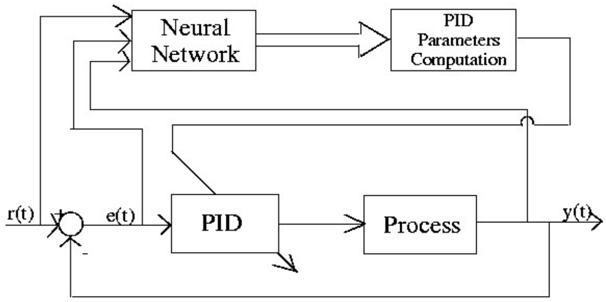

Figure 2. PID auto-tuning scheme using neural networks

For obtaining the neural network training patterns, there were simulated different kinds of systems including the PID controllers, that satisfies the required performance (IAE, ISE, ITAE, ITSE). The desired output signals are the system parameters. It was used the backpropagation learning algorithm for training the neural network.

Figure 3 illustrates the behavior of a second order system with auto-tuned PID controller using the neural network scheme and a typical one, both considering ITAE criteria. It can be seen that the response of the system using the neural scheme (solid line) presents less oscillations before reaching the steady state that the conventional scheme (dashed line).

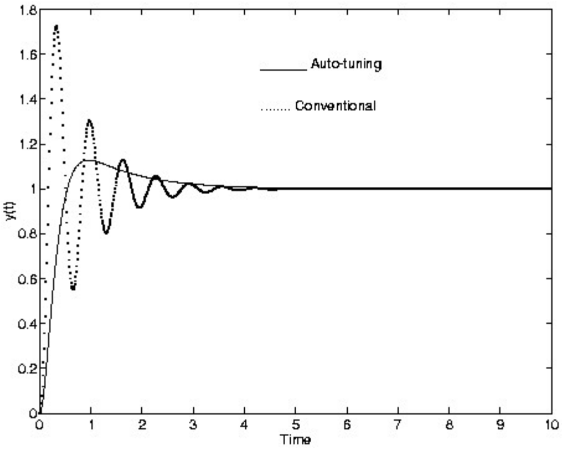

Figure 3. Close loop responses with neural and typical tuning scheme

The computer implementation of the auto-tuning scheme was developed using ***Matlab/Simulink*** according to the diagram presented in Figure 4.

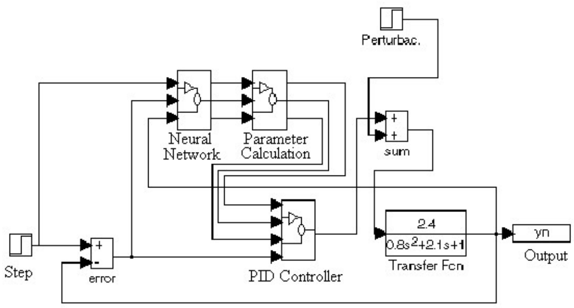

Figure 4. Computer implementation of the proposed PID Controller auto-tuning scheme

4.- CONCLUDING REMARKS

In this paper we have proposed a PID controller auto-tuning method that obtain a parametric identification of a process model via neural networks and then using the integral error criteria proceed to find on-line the PID controller gains.

The auto-tuning scheme proposed due to its simplicity may be used for controlling systems that presents parameter variations and some classes of nonlinear systems with slow dynamics.

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