ALTERNATIVE RULE BASE ADJUSTMENT METHOD ON RULE BASED CONTROLLERS

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Abstract. This paper describes a method to find a rule-base to be used on a rule based adaptive PID controller. A rule base is achieved by means of a direct method of fuzzy modelling by Takagi & Sugeno procedure by mapping a conventional virtual PID achieved by classical autotuning methods. The method proposed is an alternative method in designing neuro-fuzzy controllers.

Keywords: Fuzzy adaptive controller, Virtual training

1. INTRODUCTION AND PROBLEM STATEMENT

Usual rule base adjusting methods for PID rule based controllers are combinations of the following methods,

- Manual adjusting by an expert human operator;
- Automatic rule-base generation and regeneration by a couple of methods based in adaptation and or learning algorithms included neuro-fuzzy rule generation.

Another possibility is to associate conventional well known PID auto-tuning methods to achieve the PID parameters and then, adjust the PID rule base with the knowledge gained, by conventional autotuning procedures.

The basic idea is showed in figure 1. The method is composed of three main sub-tasks. One task is responsible for finding the parameters of a virtual PID. Another task is responsible for performing the computations needed to adjust a set of control rules (the PID rule base) using the knowledge obtained from the autotuning task. This task is equivalent to the one made by any other identification system that could have been used as well. Finally, the third task is responsible for executing the rule based control algorithm.

The rest of this paper describes these three main tasks in detail but, first, a brief discussion about autotuning oriented methods to design virtual controllers is included.

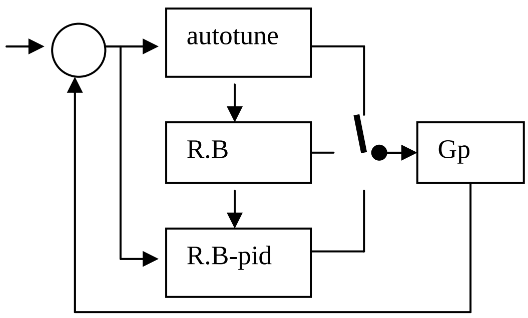

Fig. 1. The basic idea to achieve a rule based PID

1.1. *Virtual controller design*

The purpose of a virtual controller is to serve as a trainer in the task of getting a fuzzy rule-base that could be used on a PID rule based controller. To obtain a virtual (suboptimum) controller that met some dynamic requirements (i.e. increase the operational speed keeping the reduced steady state error and avoiding overshoot) one or more of the following methods can be used:

- Relay feedback auto tuning
- Frequency domain design by FFT application

1.2. *Virtual PID design by harmonic balance method*

An approximative method, called the method of harmonic balance, based in relay feedback autotuning is used. Figure 2 shows a process transfer function with a feedback ideal relay. In parallel with the feedback relay there is a rule based PID controller.

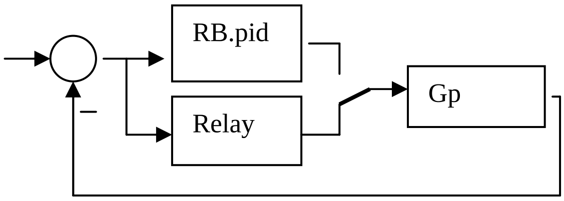

Fig. 2 Block diagram of a relay auto-tuner

An approximative condition for oscillation can be determined by assuming that there is a limit cycle with period Tu and frequency Wu = 2π/Tu such that the relay output is a periodic symmetric square wave. If the relay amplitude is d, a simple Fourier series expansion of the relay output shows that the first harmonic component has the amplitude 4d/πa. Assume further that the process dynamics are of low-pass character and that the contribution from the first harmonic dominates the output. The ultimate gain is achieved as

$$Ku = \frac{4d}{\pi a} = \frac{1}{|G(iWu)|} \qquad (1)$$

where *Ku* can be regarded as the equivalent gain of the relay for transmission of sinusoidal signals with amplitude *a*. The parameters *d, a, Tu* are shown in figure 3

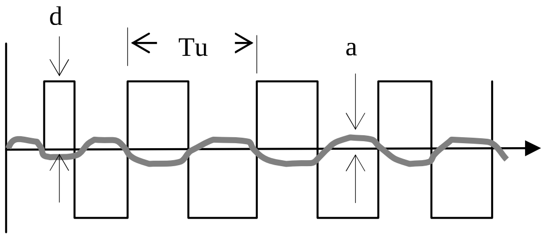

Fig. 3 Parameters of Harmonic Balance auto-tuner

Only two parameters, Ku and Tu have been obtained from the relay experiment. Table 1 shows how PID parameters are calculated from *Tu* and *Ku* using Ziegler-Nichols relations.

Table 1. Vitual PID parameters

Kp	**Ti**	**Td**
0.6.Ku	0.5 Tu	0.12 Tu

Kp	**KI=Kp/Ti**	**KD=Kp.Td**
0.6 Ku	1.2 Ku/Tu	0.072 Ku.Tu

According table 1, the virtual PID controller has been obtained by means of the ATV autotuning technique or relay feedback autotuning. This technique supplies the frequency of the limit cycle and its associated gain, known as ultimate frequency and ultimate gain respectively (Astrom and Wittenmark, 1989). Such knowledge about the process is enough to get the virtual PID controller.

1.3. V*irtual PID design by frequency response method*

This method uses a senoidal excitation instead of a relay excitation (Astrom and Hagglund, 1983). Figure 4 shows the structure of this autotuning method

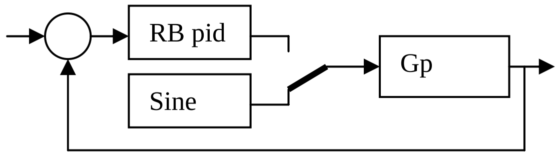

Fig. 4. Block diagram of a sine exciting auto-tuner

This method calculates the magnitude and phase at a given excitation frequency (Astrom and Hagglund, 1984). Typically, the Fast Fourier transform of the frequency response or of the time response analysis is used to get those parameters. The equations used to get the PID parameters are obtained from (Charles L. Phillips et H. Troy Nagle, J.R, 1982) and (Ferreiro et al., 2000) as,

$$\theta = 180 + \phi m - \angle Gp(jw_{W1}) \qquad (2)$$

$$Kp = \frac{Cos\theta}{|Gp(jw_{W1})|} \qquad (3)$$

$$T_D = \frac{Sin\theta + 1}{2.w_{W1}.Cos\theta} \qquad (4)$$

$$T_I = 4.T_D \qquad (5)$$

Table 2. Vitual PID parameters by frequency response analysis

Kp	**Ti**	**Td**
$\frac{Cos\theta}{\|Gp(jw_{W1}\|}$	$4.T_D$	$\frac{sin\theta+1}{2.w_{W1}.\cos\theta}$

Kp	**KI=Kp/Ti**	**KD=Kp.Td**
$\frac{Cos\theta}{\|Gp(jw_{W1})\|}$	$\frac{w_{W1}.(1-sin\theta)}{2.\|Gp(jw_{W1})\|}$	$\frac{sin\theta+1}{2.w_{W1}\|Gp(jw_{W1})\|}$

2. ACHIEVING A FUZZY PID RULE-BASE

In this section, proposed fuzzy adaptive control controllers are described. This task comprises the following automated steps:

- On line virtual (PI(D)) controller design.
- Achieving a fuzzy rule-based controller using the knowledge obtained from the virtual controller autotuning task.
- Application of the fuzzy rule based PID controller achieved.

Given a virtual controller obtained by using one of the described autotuning methods, it will be used as a trainer to get a PID rule base. The Takagi & Sugeno fuzzy modelling procedure is applied to generate the PID rule base.

Fuzzy reasoning accept several methods, direct and indirect, being the most popular the direct ones. The most popular direct methods are:

- Mamdani direct method (Mamdani, 1974)
- Simplified method
- Fuzzy modelling procedure of Takagi & Sugeno (1985) and Sugeno (1985)

Fuzzy modelling procedure of Takagi & Sugeno uses linear functions to implement the conclusion of the rules. The format of the Takagi & Sugeno rules [7] is

IF x is A AND **y** is B THEN $z = C_0 + C_1.x + C_2.y$ (6)

where C_0, C_1 and C_2 are the parameters of the linear function in the consequent of each rule. The rule base structure necessary to map the dynamics of a virtual conventional PID according the structure defined by (6), is given in table 3.

Table 3. Fuzzy modelling procedure for a virtual PID

Antecedent	Consequent
IF e = A1	THEN u1 = Kp.A1
IF Σe = A2	THEN u2 = KI.A2
IF Δe = A3	THEN u3 = KD.A3

Table 4. The consequence of the additive property

Antecedent
IF e = A1 AND
IF Σe = A2 AND
IF Δe = A3

Consequent
THEN U = Kp.A1 + KI.A2 + KD.A3

Applying the additive property to the consequent of each rule, the fuzzy rule base showed in table 4 is obtained. This rule base can be expressed in standard rule format as

$$\begin{aligned}&IF\ \ e\ is\ A1\ AND\ \Sigma e\ is\ A2\ AND\ \Delta e\ is\ A3\\ &THEN\ \ U = K_p.A1 + KI.A2 + KD.A3\end{aligned} \qquad (7)$$

Applying the autotuning techniques described in section 2 the following linear equations can be obtained:

Method of Harmonic Balance:

$$\begin{aligned}&IF\ \ e\ is\ A1\ AND\ \Sigma e\ is\ A2\ AND\ \Delta e\ is\ A3\\ &THEN\ U = 0.6\ Ku.A1 + \frac{1.2\ Ku}{Tu}.A2 + 0.072\ Ku.Tu.A3\end{aligned} \qquad (8)$$

or

$$\begin{aligned}&F\ \ e\ is\ A1\ AND\ \Sigma e\ is\ A2\ AND\ \Delta e\ is\ A3\\ &THEN\ U = 0.76\ \frac{d}{a}.A1 + \frac{1.53\ d}{a.Tu}.A2 + 0.092\ \frac{d}{a}.Tu.A3\end{aligned} \qquad (9)$$

Method of frequency response analysis:

$$\begin{aligned}&IF\ \ e\ is\ A1\ AND\ \Sigma e\ is\ A2\ AND\ \Delta e\ is\ A3\\ &THEN\ U = \frac{Cos\theta}{|Gp(jw_{W1})|}.A1 + \frac{w_{W1}.(1 - Sin\theta)}{2|Gp(jw_{W1})|}.A2 + \\ &+ \frac{Sin\theta + 1}{2.w_{W1}|Gp(jw_{W1})|}.A3\end{aligned} \qquad (10)$$

With the results of process equations (8) or (9) or (10), the PID rule base is completed.

3. SIMULATION RESULTS

Figure 5 shows the typical excitation and response signals used to design a virtual controller by using the Harmonic Balance design method.

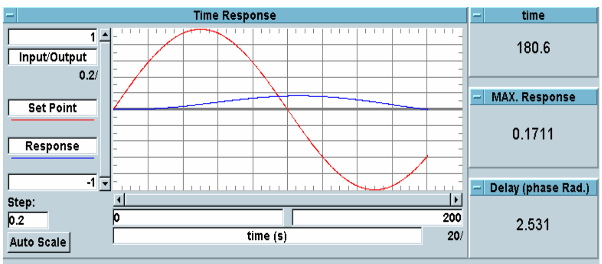

Fig 5. The Virtual controller computation

As it is shown in figure 6, the fuzzy controller is composed of three rule bases that are used in additive mode to get a crisp output.

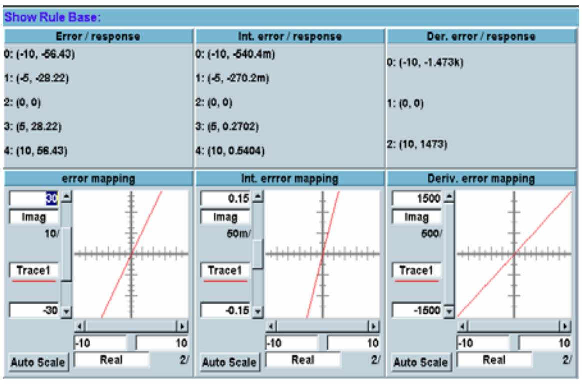

Fig 6. Resultant Fuzzy Controller (Rule-base = 13 rules)

In figure 7 the typical response of a fuzzy PID controller achieved by means of the method explained is showed.

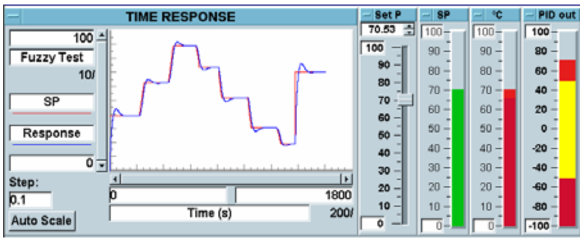

Fig. 7. The performance of the resultant fuzzy rule based PID controller

4. CONCLUSIONS

One alternative method to the design of neuro-fuzzy controllers has been presented. This method has several advantages:

- Classical or conventional autotuning techniques are well experimented.
- The time needed to achieve a rule base using autotuning techniques is shorter if compared with the training phase in neuro-fuzzy applications.
- The fuzzy reasoning procedure adopted first by Takagi & Sugeno is a proper method to achieve a fuzzy rule base with reduced number of rules.

Last topic is an advantage because an operator can easily modify the rule base, acting only in one or more premises with total independence. That means that it is possible to modify the proportional action adjusting a rule, or the derivative action, etc.

Consequently, this preliminary design study serves as the basis to continue on working to get a computer program that allows the improvement of control performance by properly adjusting the reduced rule base.

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