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Supervision of Classical PID Adaptive Regulators Using Fuzzy Logic Techniques

R. Ferreiro García and B. Rodriguez Gómez
Universidad de La Coruña
Dep. Electronica y Sistemas. E.S. Marina Civil
Paseo de Ronda 51, 15011 La Coruña

Abstract

This work describes the supervisory task of controlled plants whose strategy is based on classical adaptive PID regulators. The supervisory task includes the detection of the dynamic behaviour. According to this it decides whether to perform the autotuning, as a result of the defuzzificatión of a rule-base proposed for this purpose. The result of the fuzzy rule-base is applied in sequential mode to a deterministic rule-base (Boolean), whose conclusion serves to initiate the state of the regulator in the plant.

Keywords: Supervision, fuzzy logic, autotuning, diagnosis, fuzzy associative memory.

1 Introduction

This work describes the problem of supervising the behaviour of conventional adaptive regulators using expert and fuzzy techniques. Disturbances in feedback loops are a good test of proper regulator parameter adjustment. Such disturbances can enter the control loops from an external source, but can also be generated into the control loop due to friction of the final control elements as actuators etc. Thus, the main objective is to implement the algorithms to detect such disturbances and decide on the necessary actions to eliminate them. The task of disturbance detection is faced in order to take decisions in the parameter adjustment procedure [2]. The assumption of disturbances in the feedback loop concerns all signals that enter the feedback loop, such as changes in the reference value, high frequency noise added to the measure signal, changes in the load or parameter variation. Depending on the origin of the disturbances, the criterion for eliminating them, if possible, is of great interest. This can be carried out in different ways, depending on its origin [1]. For disturbances of an external origin, it is necessary to extinguish the causes.

Figure 1: Disturbed process. P(s)

If such a way is not possible, feedback compensation will be applied. If, on the other hand, the disturbances are generated into the feedback loop due to actuator friction, this element must be corrected conveniently. Being an industrial classic application, the process is constituted generally as a low-pass filter characteristic, which means low gain at high frequencies. The load disturbances are of great importance when their frequency belongs to the neighbourhood of the ultimate frequency due to the bad performance in adaptive control. The adaptive regulator interprets the frequency of such disturbances as high loop gain [1]. Thus, it is of great importance to detect the oscillations of this frequency and to supervise the regulator in the sense of avoiding the adjustment of parameters due to this problem. An added problem appears when the ultimate frequency of the system changes due to parameter variations. As a consequence it is necessary to investigate how the load disturbances V(s) that enter the control loop are transferred to the measure signal Y(s). The transfer function between the output Y(s) and the input R(s) and between the disturbance output V of an external origin are given in (1) and (2) and are illustrated in Figure 1.

$$\begin{aligned} G_{yr}(s) &= C(s)P(s)/[1+C(s)P(s)]) \\ G_{yv}(s) &= P(s)/[l+C(s)P(s)] \end{aligned} \quad (1)$$

The system output is due to two input signals. There is another cause of non-desired behaviour which is due to parameter variation in the process transfer function.

$$Y(s) = [V(s) + r(s)C(s)]P(s)/[l + C(s)P(s)] \quad (2)$$

A variable steady state response is mainly due to changes in the input reference, parameter variation and load changes. Except for the changes in the set value in the input reference which can rejected by means of feedforward compensation, the remaining signal changes must be detected by means of the system response analysis by identification of the load excess and the frequency of the oscillations. The procedure for detecting load disturbances can be performed by means of the analysis of the magnitude and the absolute value of the error (IAE) between successive steps by crossing zero error of the control variable. For the periods of good control performance, the magnitude of the control error is low. In this case it is assumed that the controller emits control action, and consequently the average error is null or low. To improve the procedure of oscillation detection, it is necessary to establish a proper limit value for IAE. Assuming as known the value of the integral time in T_i of the regulator, the IAE has been stated in [1] as

$$IAE_{\mathrm{lim}} = l/w_i, \text{ where } w_i = 2 * Pi/T_i \tag{3}$$

This method requires the control error shape to belong to a pure sinoid function, which makes the method improper to be applied in real time control, the most important cause being obviously the presence of load disturbances.

2 Detection of oscillations and load

In this work we assume a practical criterion which is required to avoid deterioration of control objectives due to manipulation of system variables of standard characteristics. Therefore, it is preferred to select a limit value for the IAE of each control loop in concordance with its maximum working value or limit value, as the maximum supported value without deterioration of control performance due to load disturbances.

The detection of oscillations in feedback loop is based on a rule conclusion which states that there are oscillations if the load disturbance frequency becomes high. That is, the control system dynamics behaviour is being supervised during the time T_{sup}. If due to load, the amount of oscillations N_{osc} detected exceeds the limit value, denoted as N_{lim} during that time, then the conclusion is that there is presence of oscillations. As a consequence of this reasoning the following rules can be stated:

If IAE > $\mathrm{IAE}_{\mathrm{lim}}$ then, THERE ARE LOAD OSCILLATIONS

If NOSC > $\mathrm{N}_{\mathrm{lim}}$ then, THE LOAD DISTURBANCES ARE DUE TO OSCILLATIONS

3 Decision criteria on regulator adjustment

The criteria for deciding whether to perform an autotuning task depends on its desired capacity to track a reference input signal as well as the capacity to reject load disturbances. There will be a certain compromise between both such concepts, which are in opposition with against each other. The detection in variations of the

Figure 2: Fuzzy rule-base

loop gain or another meaningful parameter is generally of much help. For the acquisition of such information the nominal math-model nominal of the control process is needed, with which it is possible to evaluate the variations in loop gain after the analysis of the time responses of both the model and the real-time process output without requiring a classical identification method.

In this way, we intend to simplify the supervision strategies in order to make the autotuning supervision algorithm reliable and safe. For this reason, it is of great importance to improve the supervisory task on the basis of human behaviour model.

In order to solve this problem we will use a fuzzy associative memory [3], FAM, which decides when the regulator will be enabled to be adjusted using its autotunung capabilities. The FAM consists of a hypercube with two input variables:

- Presence of load under IAE criteria
- Presence of oscillations

Thus, the universe of discourse of both variables may be described under the following membership functions:

- Presence of load as Z,S,M,H (zero, short, medium, high)
- Presence of oscillations as Z,S,M,H,VH (zero, short, medium, high and very high)

The universe of discourse for the output variable is defined by two membership functions sets, which are an advisor generator denominated Men, and an autotuning enabling signal (Aut) [4].

The membership function Men support three deterministic outputs:

Figure 3: Membership function sets for input/output variables

- An indicator for normal process dynamics
- presence of noise in the measured variable (rui)
- Manual mode advisor (MM)

The procedure for decision making consists in defuzzyfying of the rule-base shown in Figure 3, where (Aut) is the defuzzified output that commands the regulator for enabling the autotuning task. On the other hand, Men is the conclusion from the rule-base which, applied as an input to the deterministic rule base, completes the inference engine capable of supplying advice as shown in Figure 4, in which knowledge is stored in two memories, a FAM and a DAM (deterministic associative memory).

Figure 4: Decision-making generator

The supervision algorithm is shown in Figure 5, where the overall task is completed by scanning and processing every regulator sequentially. The history knowledge about each process must be accessible in order to compare the actual regulator

Figure 5: Supervision Task.

parameters adjusted with the proposed algorithm with the old parameters achieved by nominal models in order to validate the supervising task. With this methodology, autotuning tasks of non-desirable precision might be rejected.

The origins of excess load and the oscillations are not known because they may be due to large parameter variations or excess loads as well as to external excitations within the limit of the ultimate frequency, after an autotuning task it becomes necessary to check whether the new PI(D) parametric configuration is within the range of its limits. Such values must have been achieved under the assumption of a real time training with the maximum parameter variation and load changes. For instance, the mass of a ship can only change for a particular model between 3/4 and 1/4 its nominal value and the load due to the wind waves and current between 0 and 1/3 of the maximum control effort. This means that for each load change or prescribed parameter variation there must be a set of possible values for the regulator parameters. If after a supervision cycle and consequent updating of regulator parameters they are out of limits, then it is to be concluded that something abnormal is happening and it is interpreted as the manual mode demand to correct such a fault. The supervision task cycle is completed by scanning sequentially all regulators in which the following steps must be performed for every control loop:

- Begin the control loop i and checks IAE for load and oscillations by means of algorithms (1) and (2).

- Process the fuzzy and deterministic rule bases with updated acquired information

- Act according to rule-base conclusions:

Figure 6: Process supervision controlled by a Shimaden SR-25 autotuning regulator

(a) If Men and oscillations are null, (zero output) then the supervision task is finished for this control loop.

(b) If Men and IAE = 0 and osc = max. limit, then there is noise in the feedback loop.

(c) If Men and IAE >> 0 then manual mode is necessary

Once the autotuning task is finished, the supervision algorithm checks the PI(D) parameters to validate them by comparing the new values with the nominal ones. If the parameters are within the expected limits then this task is finished and the scan continues to another control loop. On the other hand, if the new parameters are outside the limits it is to be concluded that the system parameters have been changed too much and the inference engine passes the control to the deterministic rule base, as shown in Figure 4.

4 Implementation

The supervision task is implemented on a controlled process which consists of a level tank control controlled in feedback mode by means of an adaptive type Shimaden SR-25 PI(D) regulator with capability to implement communication with a PC computer via RS-232C bus with an 8 bit protocol.

5 Conclusion

The generation of proper information to introduce in a fuzzy rule base is a problem that has been solved in [1] and [2], among others. The application of a fuzzy supervision task on the basis of diagnosis for controlled plants was presented. Hybrid rule bases (fuzzy and deterministic) are a good solution for many problems. A conflict resolution problem is present in cases where a compromise between fuzzy and deterministic rules is present.

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