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Asymmetric relay autotuning – Practical features for industrial use

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ABSTRACT

The relay autotuner provides a simple way of finding PID controller parameters. Even though relay autotuning is much investigated in the literature, the practical aspects are not that well-documented. In this paper an asymmetric relay autotuner with features such as a startup procedure and adaptive relay amplitudes is proposed. Parameter choices and handling of noise, disturbances, start in non-steady state and other possible error sources are discussed. The autotuner is implemented and tested on an industrial air handling unit to show its use in practice. The experiments show good results, and prove that the proposed simple autotuner is well-suited for industrial use. But the experiments also enlighten possible error sources and remaining problems.

1. Introduction

In an industrial process facility with hundreds of control loops, the benefits of a simple, reliable, automatic way of tuning the controllers are obvious. The relay autotuner has proven to be a good candidate for automatic tuning of PID controllers. Some advantages of the relay autotuner are that it is fast, operates in closed loop and does not disturb the process more than necessary. Another main advantage is that it does not require any knowledge about the process a priori, since the relay feedback experiment automatically excites the process in the frequency range interesting for PID control. The short experiment time is essential, not only due to the overall time-consumption, but also since it reduces the risk of disturbances entering during the experiment.

Since the relay autotuner was introduced in the 1980s (Åström & Hägglund, 1984), many modifications of it have been proposed. Finding a low-order model from the relay experiment was proposed in Luyben (1987), where the static gain was assumed to be known and in Li, Eskinat, and Luyben (1991), where an additional relay experiment was performed. In this paper an asymmetric relay function is used. The asymmetric relay provides a better excitation of the process at lower frequencies than its symmetric counterpart, without making the experiment any more complicated or time-consuming. The original autotuner only gave two parameters, but with an asymmetric relay the low-order models found in e.g. Luyben (1987) and Li et al. (1991) could be found from a single relay experiment without any prior process knowledge. A version of the asymmetric relay function was used in Shen, Wu, and Yu (1996a), and later investigated in e.g. Kaya and Atherton (2001a), Lin, Wang, and Lee (2004) and Berner, Åström, and Hägglund (2014). For a more thorough review of the advances in modeling from relay feedback experiments, see Liu, Wang, and Huang (2013).

Although much research has been done on both symmetric and asymmetric relay autotuners, our experience is that focus is seldom on the practical use of the autotuner. Instead exactness or closeness to the true model under ideal simulation conditions is often considered. In this paper we aim for a more practical approach. We use simple low-order models that will of course never describe the true processes exactly. However, the aim is not to get perfect models, but rather to get a good-enough model for tuning a well-performing controller. The focus of this paper is more on practical aspects such as how to choose the experiment parameters and how the models are affected by noise or other disturbances entering the experiment. These investigations are mainly made in a simulation environment and described in Section 4. The autotuner is also tested in a real industrial setting, which is documented in Section 5. The industrial tests were performed on two subsystems of an air handling unit. The experiments were exposed to many of the problems that may be encountered in practice, but still gave overall good results with well-performing controller tunings.

2. Automatic tuning

The purpose of the autotuner is to give satisfactory controller parameters for a process with completely unknown dynamics. To

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do this, the autotuner goes through the different steps shown in Fig. 1, where each step contains actions and decisions to be performed.

The first step is the *Experiment*, where it has to be decided what type of experiment should be done, and how it should be designed. It is also decided what experiment parameters should be used, and what data should be extracted from the experiment. In this paper the experiment is the asymmetric relay feedback experiment, described further in Section 3.

The *Model* step includes decisions on what model structure to use. It should also contain a method to obtain the desired model parameters. In this work, the estimated model structure depends on the value of the normalized time delay τ, defined as

$$\tau = \frac{L}{L+T}, \quad 0 \le \tau \le 1, \tag{1}$$

where L is the apparent time delay and T is the apparent time constant of the process. The model structure choice is made according to the decision scheme in Fig. 2, proposed in Berner (2015), Berner, Hägglund, and Åström (2016). This paper focuses on the simple version where either a first order model with time delay, FOTD model

$$P(s) = \frac{K_p}{1+sT} e^{-Ls}, \tag{2}$$

or an integrating model with time delay, ITD model

$$P(s) = \frac{k_v}{s} e^{-Ls}, \tag{3}$$

is calculated from the experiment.

When the model is found a *Controller* should be designed. This step includes decisions about what controller type to use and how to choose its parameter values. In this paper we use the PID controller on the form

$$C(s) = K\left(1 + \frac{1}{sT_i} + sT_d\right) \tag{4}$$

tuned from the AMIGO rules (Åström & Hägglund, 2006) for the obtained models. Changing to another tuning method is straightforward. The choice of whether or not to use the D-part of the controller can be based on the scheme in Fig. 2.

The final step is the *Evaluation* of the results. Here it is decided if the performance of the obtained controller is satisfactory, or if something should be changed in the previous steps. This is mainly a task for the user. One possibility is to use the transient after the experiment as validation data, to see if it agrees with the expected behavior of the obtained process model. Separate evaluation experiments of the controller performance, measuring for instance the integrated absolute error for an added load disturbance, could also be performed.

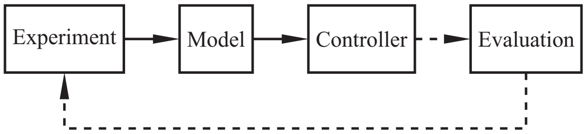

Fig. 1. Steps to be designed and performed in an automatic tuning procedure. The dashed lines show the steps that involve the user.

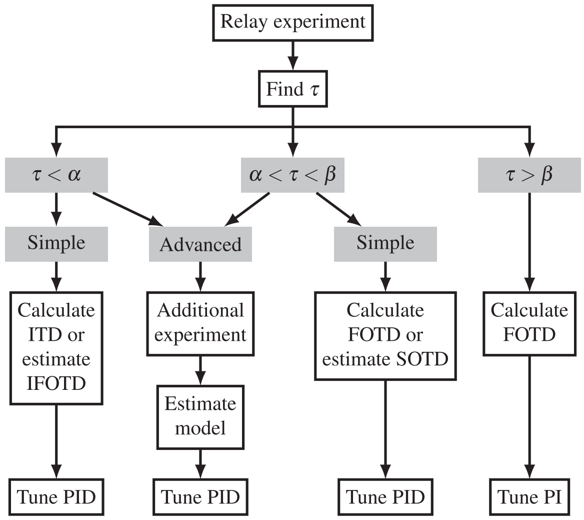

Fig. 2. Decision scheme based on the normalized time delay τ. The limits for low and high values of τ are set to $\alpha = 0.1$, $\beta = 0.6$ as in Berner (2015).

3. Asymmetric relay feedback

The experiment sequence is shown in Fig. 3. This section describes the two last steps, the relay feedback and the retrieval of data, while the practical issues of the first steps are described in Section 4.

Let u denote the output signal from the relay function, and y denote the process output signal. The asymmetric relay experiment is started when the system is at equilibrium at the point (u_0, y_0). The asymmetric relay function proposed is

$$u(t) = \begin{cases} u_{\text{on}}, & y(t) < y_0 - h, \\ u_{\text{on}}, & y(t) < y_0 + h, \ u(t^-) = u_{\text{on}}, \\ u_{\text{off}}, & y(t) > y_0 - h, \ u(t^-) = u_{\text{off}}, \\ u_{\text{off}}, & y(t) > y_0 + h, \end{cases} \tag{5}$$

where h is the hysteresis of the relay and $u(t^-)$ is the value u had the moment before time t. The output levels of the relay, u_{on} and u_{off}, are defined as

$$u_{\text{on}} = u_0 + d_1 \operatorname{sign}(K_p), \quad u_{\text{off}} = u_0 - d_2 \operatorname{sign}(K_p). \tag{6}$$

The sign of the process gain K_p (or k_v if the process is integrating) is determined during the startup of the experiment, as will be

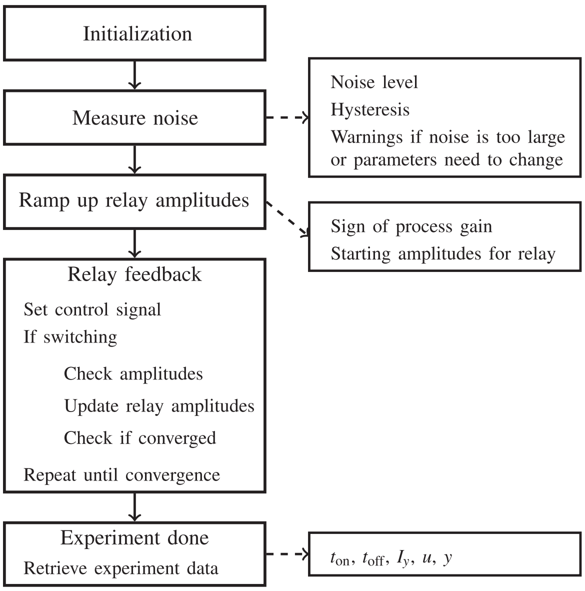

Fig. 3. The different sequences of the relay feedback experiment. Also shown are the variables and parameters obtained in that sequence.