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Comparisons and Experimental Validation of Several Autotuning Methods for Fractional Order Controllers

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Abstract: Accurate process modelling is occasionally difficult. In such situations, autotuning methods enable the design of controllers. Fractional order PIDs have recently emerged as generalization of the standard PIDs, but autotuning methods for these controllers are scarce. In this paper, a new approach is described, based on an extension of the widely-used Ziegler-Nichols method. Comparative tests with two other autotuning methods are performed on a highly non-linear process. The experimental results validate the proposed method.

Keywords: auto-tuning; fractional order; experimental validation; vertical take-off and landing

1. Introduction

The fractional order PID (FO-PID) controller was first introduced by Podlubny [1]. It allows for improved closed loop response and robustness, due to the two supplementary tuning parameters involved, $0 < \lambda, \mu < 1$, the fractional orders of integration and differentiation. The transfer function of the FO-PID controller is described as:

$$C_{FO-PID}(s) = k_p \left(1 + \frac{1}{T_i s^{\lambda}} + T_d s^{\mu}\right) \tag{1}$$

where k_p is the proportional gain, while T_i and T_d are the integral and derivative time constants. In this manuscript, we assume $\lambda = \mu$ and $T_i=4\cdot T_d$ [2]. In a large area of applications, including aeronautics, accurate process models are difficult to be obtained. Autotuning methods are preferred in this case, as the popular Ziegler-Nichols approach [2]. The method produces acceptable results in terms of disturbance rejection, but poor results regarding setpoint tracking. Autotuning designs for FO-PID controllers are however scarce. Three autotuning methods for FO-PIDs are compared in this manuscript. One of these is a novel extension of [2]. To obtain the necessary process information, a relay test is used. The process critical frequency and critical gain are obtained in this way.

The proposed method is based on shaping the "direction" of the loop frequency response in a fixed point in the Nyquist plot, corresponding to the critical frequency. It is determined that for a given fractional order of the FO-PID controller, tuning rules similar to the Ziegler-Nichols method can be obtained. The parameters of the FO-PID controller can thus be easily computed, without any complex optimization procedure. For a given fractional order λ, the parameters k_p, T_i and T_d of the Ziegler-Nichols FO method can be computed as indicated in Table 1> Notice that for $\lambda = 1$, the standard parameters of the Ziegler-Nichols method are obtained.

Table 1. FO-PID parameters according to the modified Ziegler-Nichols method

λ	k_p	T_i	T_d
0.4	$0.16k_c$	$2.27T_c^{0.4}$	$0.57T_i$
0.6	$0.29k_c$	$1.12T_c^{0.6}$	$0.44T_i$
0.8	$0.42k_c$	$0.71T_c^{0.8}$	$0.33T_i$
1	$0.6k_c$	$0.5T_c^{1.0}$	$0.25T_i$

2. Results and Discussion

The proposed autotuning method is tested on a Vertical Take-Off and Landing (VTOL) system as described in [3]. The designed fractional order controller is implemented on the VTOL unit. The experimental results are given in Fig. 1. For comparative purpose two other FO-PI controllers are implemented. These are designed according to the auto-tuning methods presented in [4] and [5].

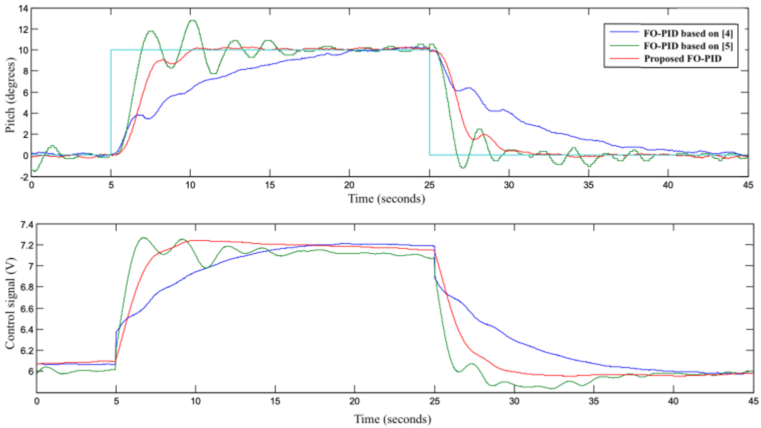

Fig. 1. Experimental closed-loop system response of the VTOL platform with the FO-PID controllers

3. Concluding Remarks

A new auto-tuning method extending the popular ZN approach to fractional order controllers is described in this paper. To validate the method, comparisons with other autotuning methods are performed on a VTOL unit. The experimental results clearly demonstrate that these autotuning methods can be successfully used to control highly nonlinear and poorly damped systems.

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