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IFAC-PapersOnLine 49-9 (2016) 164–168

Fractional PID Controller Design Based on Minimizing Performance indices

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Abstract: This paper presents a new design method for fractional PID controller. The method consist of minimizing performance index criterion. The fractional PID controller are achieved by means of diffusive representation.The minimization criterion are posed directly to the fractional order of derivative and integral operators. Simulation and results are presented to show the effectiveness of the proposed method.

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Keywords: Fractional-order operators, fractional PID controller, parameters tuning, diffusive representation, performance index

1. INTRODUCTION

Despite the enormous increase techniques and methods in control systems theory, the PID controller remains the most widely used controller in the industrial engineering. Not only for its simplicity, but for its ability to achieve the desired results. In order to enhance the performance of the closed loop controlled system, fractional derivative are used to modified classical PID structure. The idea is to extend the order of the derivative and integral actions to real values (Podlubny (1999)).

In the other hand, these controllers have two extra parameters in comparison with classical PID . Therefore classical design method may not be applied directly to adjust all fractional controller parameters.

Several research works have proposed new design techniques and tuning rules, for fractional controllers . Some of them are based on an extension of the classical control theory. In Valério and da Costa (2006) a tuning method for fractional PID controller based on Ziegler-Nichols-type rules was proposed. A state-space tuning method based on pole placement was also used (see Dorcak et al. (2001)).

In Boudjehem et al. (2013) fractional order model are used to predict the process output using smith predictor for fractional order.

In Boudjehem and Boudjehem (2013) analytical design method was proposed. The mehod are based on using fractional order system as refernce model.

Padula et al. (2014) was presented a fractional-order proportional-integral-derivative controller design based on the solution of an inline image model matching problem for fractional first-order-plus-dead-time processes.

Many methods for control design are based on optimization techniques. The common approach is to minimize a performance index (Aström and Hägglund (1995)).

An optimization approach was proposed in Monje et al. (2004), for the PI fractional controller tuning. A nonlinear functional minimization subject to some given nonlinear constraints are solved using matlab minimization function. In Leu et al. (2002), an optimal fractional order PID controller based on specified gain and phase margins with a minimum ISE criterion has been designed by using a differential evolutionary algorithm. Tuning fractional PID controller based on ITAE criterion by using Particle Swarm Optimization has been also presented in Maiti et al. (2008).

An intelligent optimization method for designing fractional order PID controller based on Particle Swarm Optimization (PSO) was presented (see Cao and Cao (2006)).

In Tavazoei (2010) the infiniteness and finiteness of different performance indices in class of fractional-order systems have been presented.

In Das et al. (2012) parameters of fuzzy fractional order controller are optimally tuned using genetic algorithm by minimizing integral error indices. In Sharma et al. (2014) Fractional Order Fuzzy Proportional-Integral-Derivative (FOFPID) controller are used and Cuckoo Search Algorithm (CSA) optimization technique are used to adjust the parameters controllers.

In Ghazbi and Akbarzadeh (2015) an optimization method based on the Tabu Search Algorithm (TSA) are used to design a Fractional-Order Proportional-Integral-Derivative (FOPID) controller.

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Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.07.522

In this paper we propose a tuning method for fractional PID controller based on ominimizing performance indices such as Integral Absolute Error(IAE), Integral Square Error (ISE) and Integral Time Absolute Error(ITAE), by means of diffusive representation. The mathematical formulation of the optimization problem are posed directly to fractional parameters. Simulation results show the effectiveness of the proposed design method in comparison with classical controller. The paper is organized as follows. In Section 2 an overview on fractional order system are given. Section 3 presents the proposed tuning mehod. Section 4 presents a simulation and results of the proposed method. Finally, a conclusions are stated in section 5.

2. FRACTIONAL ORDER SYSTEM

2.1 Fractional order differential equation

The fractional differential equation is a differential equation given by:

$$\sum_{i=1}^{N} a_i D^{\alpha_i} y(t) = \sum_{j=1}^{M} b_j D^{\alpha_j} e(t) \tag{1}$$

where D is the derivative operator, the (α_i,α_j) are the orders of differintegration and the (a_i,b_i) are constant coefficients.

There are several different definitions of fractional operators (see Oldham and Spanier (1974) and Miler (1993)). One of the most used definition of the fractional integration is the Riemann-Liouville definition

$$D^{-\alpha} f(t) = \frac{1}{\Gamma(\alpha)} \int_0^t (t-\tau)^{\alpha-1} f(\tau) d\tau \tag{2}$$

where

$$\Gamma(\alpha) = \int_0^\infty t^{\alpha-1} e^{-t} dt \tag{3}$$

is the Gamma function, α is the order of the integration.

The Laplace transform of the fractional integral given by Riemann-Liouville, under zero initial conditions for order α is :

$$L\left(D^{-\alpha} f(t)\right) = s^{-\alpha} F(s) \tag{4}$$

where $F(s)$ is the normal Laplace transformation $f(t)$.

By taking the Laplace transform of the equation 1, we obtain the transfers function of the fractional order system with input and output are $e(t)$ and $y(t)$ respectively

$$G(s) = \frac{\sum_{i=1}^{N} a_i s^{\alpha_i} Y(s)}{\sum_{j=1}^{M} b_j s^{\alpha_j} E(s)} \tag{5}$$

.

2.2 Fractional derivative implementation

There are several approaches that have been used to implement fractional order integration (see Point and Trigeassou (2002), Oustaloup et al. (2000) and Montseny (2004)). In this paper, we adopt the so-called diffusive approach (Montseny (2004))

The diffusive realization of the pseudo differential operator H, with impulse response h, $u \to g = H\left(d/dt\right) u$ is defined by the dynamic input-output system:

$$\begin{cases} \partial_t \varphi(\xi,t) = -\xi \varphi(\xi,t) + u(t) \\ g(t) = \int_0^\infty \mu(\xi) \varphi(\xi,t) \, d\xi \\ \varphi(\xi,0) = 0, \quad \xi \succ 0 \end{cases} \tag{6}$$

The system (6) is the diffusive realization of H.

The impulse response $h(t)$is expressed from $h(t)$ by:

$$h(t) = \int_0^{+\infty} e^{-\xi t} \mu(\xi) \, d\xi \tag{7}$$

so the diffusive symbol is also given by: $\mu = L^{-1} h$

The transfer function of the operator H is given by:

$$H(s) = \int_{-\infty}^{+\infty} \frac{\mu(\xi)}{s+\xi} d\xi \tag{8}$$

For example the diffusive symbol of the fractional integrators of order α

$$H\left(\frac{d}{dt}\right) = \left(\frac{d}{dt}\right)^{-\alpha}, 0 < \alpha < 1 \tag{9}$$

may be expressed as (see Laudebat et al. (2004)):

$\mu(\xi) = \frac{\sin(\pi\alpha)}{\pi} \frac{1}{\xi^\alpha}$, $\xi > 0$ where α is the order of integration.

3. FRACTIONAL PID PARAMETERS TUNING

3.1 Fractional PID controller ($PI^\lambda D^\mu$)

Fractional $\mathrm{PI}^\lambda \mathrm{D}^\mu$ controller is described by a fractional differential equation

$$K_p \left(e(t) + \frac{1}{T_i} D^{-\lambda} e(t) + T_d D^\mu e(t) \right) = u(t) \tag{10}$$

where D is the derivative operation, K_p is the proportionally gain, T_i is the integration constant, T_d is the derivative constant, λ is the integration order and μ is the derivative order. The Laplace transform of (10), lead to the following transfer function of the fractional PID controller

$$C(s) = K_p \left(1 + \frac{1}{T_i} s^{-\lambda} + T_d s^\mu \right) \tag{11}$$

We note that the classical PID controller is a fractional PID with $\mu = 1$ and $\lambda = 1$.

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