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The tuning principle of adaptive fuzzy fractional-order PID controller parameters

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Abstract

Using fuzzy method to adjust adaptive controller is fuzzy adaptive controlling, so-called adaptive controlling is that using modern control theory to recognize object's characteristic parameters online and change their control strategies timely so that control system's quality index could keep in the best range. Fractional order controller $PI^{\lambda}D^{\mu}$ became a hot pot in recently years, when compared it with the common PID controller's system we found that the former has shorter rise time, no overshoot or oscillations, and has stronger robustness. Especially, when the system has nonlinear and time-varying links, the adjusting effects will be excellent. Then the simulation of the fractional order controller $PI^{\lambda}D^{\mu}$ combination with the adaptive controlling is carried out based on Matlab in this text.

Keywords: fractional order PID controller, fuzzy adaptive controller, robustness

1. Introduction

In industrial production process, many charged objects often face the effects of load or disturbance, so its characteristic parameters or structure are frequently changed. It is impractically, if the controller has been using fixed strategy to control or manually modifying strategy to meet the change of the object's characteristic parameters, thus adaptive controller was used by more and more people in this situation. Adaptive controlling recognize object's characteristics parameters online by using modern control theory, change control strategy on time, keep the control system's quality index in the best range. But the fuzzy control is established on the basis of artificial experience. In industrial production, some complex production process using common control strategy can't achieve satisfactory control effect, for a skilled operator often take ably appropriate measures to control a complicated process by using rich practical experience. If these experiences were summarized and described by words we will get a qualitative, not precise control rule, when use the fuzzy mathematical method to quantify the rule just formed today's the fuzzy control theory. Now we combine the fuzzy control theory that has the ability to solve complex problems, the

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adaptive controller that can automatically adjust the control strategy and the fractional controller that has very good adjust effect to nonlinear time-varying links, we will get the best control effect.

2. Fractional order $PI^{\lambda}D^{\mu}$ controllers(FOPID)

Fractional order control system is described by fractional order differential equations. Fractional calculus allows the derivatives and integrals to be arbitrary order. The FOPID controller is the expansion result of the conventional PID controller based on fractional calculus. FOPID controllers design parameters have five and improve the design flexibility.

The general calculus operator (including fractional order and integral order) is defined as:

$$ {}_aD_t^{\alpha} = \begin{cases} \dfrac{d^{\alpha}}{dt^{\alpha}}, & \mathrm{Re}(\alpha) > 0 \\ 1, & \mathrm{Re}(\alpha) = 0 \\ \int_a^t (d\tau)^{-\alpha}, & \mathrm{Re}(\alpha) < 0 \end{cases} \tag{1} $$

There are several definitions of fractional derivatives as fellows:

(1) Grunwald-letnikov definition

$$ {}_aD_t^{\alpha} f(t) = \lim_{h \to 0} h^{-\alpha} \sum_{j=0}^{\left[\frac{t-a}{h}\right]} (-1)^j \binom{\alpha}{j} f(t - jh) \tag{2} $$

Where $[\bullet]$ is a truncation; $\binom{\alpha}{j}$ is binomial coefficients

(2) Riemann-Liouville definition

$$ {}_aD_t^{\alpha} f(t) = \frac{1}{\Gamma(n-a)} \frac{d^n}{dt^n} \int_a^t \frac{f(\tau)}{(t-\tau)^{\alpha-n+1}} d\tau \tag{3} $$

Where n-1< α <n; $\Gamma(\bullet)$ is the Euler Gamma function

(3) Caputo definition

$$ {}_aD_t^{\alpha} f(t) = \frac{1}{\Gamma(n-a)} \int_a^t \frac{f^{n}(\tau)}{(t-\tau)^{\alpha-n+1}} d\tau, \ (n-1 < \alpha < n) \tag{4} $$

FOPID is developed on the basis of fractional order calculus, it is the general form of the integer traditional PID, besides the three parameters of integral PID controller, FOPID has two parameters that is integral order λ and differential order μ and the value is any real. After introducing the two parameters, the system transfer function is described by:

$$ u(t) = k_p e(t) + k_i D^{-\lambda} e(t) + k_d D^{\mu} e(t) \tag{5} $$

The continuous transfer function of FOPID is obtained through Laplace transform, which is given by:

$$ G(s) = k_p + \frac{k_i}{s^{\lambda}} + k_d s^{\mu} \tag{6} $$

After the discrete time, the (5) is described by:

$$ u(k) = k_p e(k) + k_i h^{\lambda} \sum_{j=0}^{k} q_j e(k-j) + k_d h^{-\mu} \sum_{j=0}^{k} d_j e(k-j) \tag{7} $$

Where $e(k) = rin - yout(k)$, $q_j = (1 - \frac{1+\lambda}{j}) q_{j-1}$, $d_j = (1 - \frac{1-\mu}{j}) d_{j-1}$, $q_0 = d_0 = 1$