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The simulation analysis for a kind of fractional order kalman estimator

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Abstract

A kind of Kalman estimation algorithm will be presented based on model conversion. With the heating furnace system as a application background, the simulation analysis is made applying the MATLAB/Simulink toolbox. Compared with the fractional order Kalman estimation algorithm based on the fractional order state-space model, the proposed method is more easily to be realized. Moreover, the estimation accuracy of the proposed fractional order Kalman estimator is higher than that of the integer order Kalman estimator.

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Keywords: Fractional order system, state estimation, Kalman filtering, simulation, Simulink

1. Introduction

Compared with the traditional integral order calculus, the fractional order calculus can gives a more accurate description[1,2]. With the development of industry, the modeling requirement for some actual models is higher and higher. So far fractional order calculus has been widely applied in many industrial processes such as metallurgy, chemical industry, electric power, light industry and machine. Moreover, its development also provides the new theoretical principle for the development of each discipline[3,4]. Now the study on the state estimation problem for fractional order systems has taken another step forwards. Three kinds of linear fractional order Kalman filtering

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algorithms have been presented by refs[5,6]and[7] separately. Ref[8] gives a kind of nonlinear fractional order Kalman filtering algorithm. But the computational burden is great and the algorithm is more complex due to the complexity of fractional models in the above results.

In this paper, the design and analysis for the Kalman estimator of fractional order systems are given from a new perspective. With the heating furnace system as a application background, a kind of fractional order Kalman estimator is presented based on the model transformation. And the simulation analysis of the Kalman estimator is also given for the integral and fractional order models. It shows that the description accuracy of the fractional order model is better than that of the integral order model. The model transformation yields the loss of accuracy, but the estimation accuracy of the Kalman estimator for the fractional order model is higher than that for the integral order model.

2. Fractional order Kalman estimation algorithm based on the model transformation

2.1. Kalman estimation algorithm for integral order systems

Consider the following linear stochastic system

$$x(k+1) = \Phi x(k) + \Gamma w(k) \tag{1}$$

$$y(k) = Hx(k) + v(k) \tag{2}$$

where $x(k) \in R^n$ is the state of system at time k, $y(k) \in R^m$ is the measurement signal for the state, $w(k) \in R^r$ is the input white noise, $v(k) \in R^m$ is the measurement noise. Φ, Γ, H are known constant matrices.

Assumption 1. $w(k)$ and $v(k)$ are uncorrelated white noises with zero means and the covariance matrices Q and R,

$$\mathrm{E}[w(k)] = 0,\ \mathrm{E}[v(k)] = 0,\ \mathrm{E}[w(k)w^{\mathrm{T}}(l)] = Q\delta_{kl},\ \mathrm{E}[v(k)v^{\mathrm{T}}(l)] = R\delta_{kl},$$

$$\mathrm{E}[w(k)v^{\mathrm{T}}(l)] = 0, \quad \forall k,l \tag{3}$$

Assumption 2. $x(0)$ is uncorrelated with $w(k)$ and $v(k)$,

$$\mathrm{E}[x(0)] = \mu_0,\ \mathrm{E}[(x(0)-\mu_0)(x(0)-\mu_0)^{\mathrm{T}}] = P_0 \tag{4}$$

The Kalman prediction problem for integral order system is to obtain de linear minimum variance estimator $\hat{x}(k \mid k+N)$, $N > 0$ for the state $x(k)$ based on the measurements $(y(1), \cdots, y(k))$.

Compared with the fractional order model, the integral order system has a simpler state-space model, which yields the integral order state estimation algorithm is more easily to be realized. In this paper, taking above advantage of integral order estimator, the state estimation of fractional order system is made based on the integral order state estimator after a approximate transformation of model. Lemma 1 gives a integral order Kalman estimation algorithm, which will be applied.

Lemma 1[9] For the system (1) and (2) with assumptions 1 and 2, the recursive Kalman estimator $\hat{x}(k \mid k+N)$ ($N > 0$) is given by

$$\hat{x}(k \mid k+N) = \hat{x}(k \mid k+N-1) + K(k \mid k+N)\varepsilon(k+N) \tag{5}$$