



Sliding mode state and parameter identification for linear stochastic systems

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Abstract

This paper presents the sliding mode mean-square and mean-module state filtering and parameter identification problems for linear stochastic systems with unknown parameters over linear observations, where unknown parameters are considered Wiener processes. The original problems are reduced to the sliding mode mean-square and mean-module filtering problems for an extended state vector that incorporates parameters as additional states. The obtained sliding mode filters for the extended state vector also serve as the optimal identifiers for the unknown parameters. Performance of the designed sliding mode mean-square and mean-module state filters and parameter identifiers are verified for both, stable and unstable, linear uncertain systems.
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1. Introduction

Since the sliding mode control was invented in the beginning of 1970s (see a historical review in [1–3]), it has been applied to solve several classes of problems. For instance, the sliding mode control methodology has been used in stabilization [4,5], tracking [6,7], observer design [8–10], frequency domain analysis [11], and other control problems. Promising modifications of the original sliding mode concept, such as integral sliding mode [12] and higher order sliding modes [13,3], have been developed. Application of the sliding mode method is then extended to Markovian systems [14–17], stochastic systems [18–21] and stochastic filtering problems [22,23].

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The problem of the optimal simultaneous state estimation and parameter identification for stochastic systems with unknown parameters has been systematically treated beginning from the seminal paper [24]. The optimal result was obtained in [24] for a linear discrete-time system with constant unknown parameters within a finite-time filtering interval, using the maximum likelihood principle, in view of a finite set of the state and parameter values at time instants. The application of the maximum likelihood principle was continued for linear discrete-time systems in [25] and linear continuous-time systems in [26]. Nonetheless, the use of the maximum likelihood principle reveals certain limitations in the final result: (a) the unknown parameters are assumed constant to avoid complications in the generated optimization problem and (b) no direct dynamical (difference) equations can be obtained to track the optimal state and parameter estimates dynamics in the “general situation,” without imposing special assumptions on the system structure.

This paper presents the sliding mode optimal filter and parameter identifier for linear stochastic systems with unknown parameters over linear observations, which is based on the sliding mode-like input of the innovations process. A historical development of sliding mode control can be observed in [1–3]. The filtering problem is formalized considering the unknown parameters as additional system states, Wiener processes, satisfying linear stochastic Ito equations with zero drift and unit diffusion. Thus, the problem is reduced to the sliding mode filter design problem for bilinear systems with unmeasured states, whose solutions are obtained in [29] and [30], respectively. This presents the optimal algorithm for simultaneous state estimation and parameter identification in linear systems with unknown multiplicative and additive parameters over linear observations. Note that since the original identification problem is reduced to the sliding mode filtering problem for the extended system state including both state and parameters, the identifiability condition for the original system coincides with the observability condition for the extended system.

The paper is organized as follows. Section 2 presents the filtering and parameter identification problem statement for a linear system state with unknown multiplicative and additive parameters over linear observations. In Section 3, the stated problem is reduced to the sliding mode filtering problem for an extended state vector that incorporates parameters as additional states. The optimal filtering equations are then obtained. In Sections 4 and 5, performance of the designed sliding mode mean-square and mean-module filters is verified for linear systems with an unknown multiplicative parameter over linear observations, respectively. Both, stable and unstable, linear systems are examined for each sliding mode filter. The simulation results demonstrate reliable performance of the filter: in both cases, the state estimate converges to the real state and the parameter estimate converges to the real parameter value rapidly.

2. Filtering problems for linear systems with unknown parameters

Let (Ω, F, P) be a complete probability space with an increasing right-continuous family of σ -algebras $F_t, t \geq t_0$, and let $(W_1(t), F_t, t \geq t_0)$ and $(W_2(t), F_t, t \geq t_0)$ be independent Wiener processes. The F_t -measurable random process $(x(t), y(t))$ is described by a linear differential equation with an unknown vector parameter $\theta(t)$ for the system state

$$\begin{aligned} dx(t) &= (a_0(\theta, t) + a(\theta, t)x(t)) dt + b(t) dW_1(t), \\ x(t_0) &= x_0, \end{aligned} \tag{1}$$

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