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Decentralized PI tracking control for non-Gaussian large-scale interconnected distribution systems ☆

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Abstract

This paper addresses a novel constrained decentralized shaping control problem for a class of nonlinear large-scale interconnected distribution systems. Such systems are generated by multiple output conditional probability density functions (PDFs) and exist in multi-channel non-Gaussian stochastic processes. Following a decoupled B-spline approximation to the output conditional PDFs, the large-scale interconnected weight systems are introduced to characterize the correlation in different weight vectors and further to describe the dynamic relation between the control input and weight vectors. The decentralized PI controller with delay dependent analysis is designed to ensure the system stability and convergence of the dynamic tracking error to zero. Moreover, the $L_2 - L_\infty$ norm from the disturbance to the controlled output is reduced to a prescribed level and the state constraint requirement can also be guaranteed. The effectiveness of the developed algorithm is verified by simulations of paper making process.

1. Introduction

Recently, different from any classical Gaussian-based control approaches, a series of novel control strategies which control the shape of output probability density functions (PDFs) for non-

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Gaussian stochastic processes have received considerable attention (see, e.g., [1–5]), which is also called the stochastic distribution control (SDC) problem. The new control framework can improve the defects that only the mean and the variance can be controlled for general Gaussian systems, thus further satisfying the control requirements of complex non-Gaussian closed-loop systems. For the infinite-dimensional control coupled with nonnegative and constrained PDFs, the decoupled B-spline function was introduced to approximate the output distribution and further convert the PDF shaping control into the control of finite-dimensional weight vectors (see [1,4]). Some effective optimization approaches were proposed to solve the non-Gaussian stochastic control problems in [2]. In [5] the first-order stochastic distribution process was discussed, while the linear model with PID controller was studied in [6]. The tracking control was proposed in [7] for a specified stationary density function. The discrete-time PI controller in SDC and the two-step intelligent modeling method were established in [8,9], respectively. The support vector machine was adopted to establish the PDF model in [10] and the statistic information control framework in SDC was proposed in [11]. Recently, in [12,13] the sliding-mode technique and robust control were considered respectively to tackle the dynamic tracking for PDFs. Moreover, the fault detection and tolerant control in SDC were dealt with in [14–16]. However, in most of the SDC results, only single output PDF is considered as the controlled objective and the modeling and control problem is discussed within an independent control channel, which severely restricts the range of applications and the development of SDC theories. Theoretically, it is very necessary to explore the modeling and control problem for multiple PDFs in different control channels generated by complex large-scale non-Gaussian processes, especially when the multiple stochastic outputs are probabilistically mutually influenced.

On the other hand, there has been an increasing interest in the development of theories and related algorithms for large-scale interconnected systems because of its various applications [17]. It is noted that many practical systems are large-scale models and consist of interconnected subsystems in the real world. Among a large number of research results, decentralized control schemes present a practical and effective means for reducing the complexity of control implementation for large-scale systems (see [18–22]). Furthermore, as a frequent source of instability, the time delay problem, especially the delay-dependent stabilization analysis with linear matrix inequality (LMI) approach, has been widely studied in recent years (see [23–25] and the references therein). For the large-scale system with time delays, some results have also been reported on the decentralized delay-dependent stabilization via the LMI approach (see, e.g., [26–30]). In [26] the problem of decentralized stabilization was studied for a class of large-scale stochastic time-delay systems. A free weighting method with LMI was developed to deal with the problem of delay-dependent stability in [27,28], while the decentralized H_∞ stabilization feedback control with interval time-varying delay was discussed in [29]. In [30], the interconnected terms were assumed to be nonlinear and meet a quadratic bounding inequality. To date, however, few results focus on the dynamic tracking problem with delay-dependent performance and the disturbance attenuation problem for larger-scale systems. As a result, the motivation of this paper is to build the large-scale interconnected weight models for characterizing the probabilistic correlation between different PDFs and further discuss the corresponding multi-objective control problem.

With the motivations as described above, there is no doubt that the shaping control for multiple PDFs with different channels can also be viewed as a novel nonlinear decentralized control problem for large-scale interconnected stochastic distribution systems. The contributions of this paper are mainly summarized in the following aspects. (i) The conditional PDFs of stochastic outputs, instead of the common PDFs, are first considered as the new control objective