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A new calculation method of feedback controller gain for bilinear paper-making process with disturbance

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ABSTRACT

This paper presents a new method to calculate the feedback control gain for a class of multivariable bilinear system, and also applied this method on the control of two sections of paper-making process with disturbance. The robust $H\infty$ control problem is to design a state feedback controller such that the robust stability and a prescribed $H\infty$ performance of the resulting closed-loop system are ensured. The controller turns out to be robust with respect to the disturbance in the plant. Utilizing the Schur complement and some variable transformations, the stability conditions of the multivariable bilinear systems are formulated in terms of Lyapunov function via the form of linear matrix inequality (LMI). The gain of controller will be calculated via LMI. Finally, the application examples of a headbox section and a dryer section of paper-making process are used to illustrate the applicability of the proposed method.

1. Introduction

During last recent years, bilinear systems have been widely applied to a wide variety of fields, for example, engineering, biology, and economics. A bilinear system exists between linear and nonlinear systems, and its dynamic is simpler than that of nonlinear systems. Also, a bilinear model can obviously represent the dynamics of a nonlinear system more accurately than a linear one. In many practical systems bilinear systems arise as natural models where the bilinearity of states and control variables appears naturally, for example paper-making process, distillation columns, DC motors, induction motor drives, mechanical brake systems, nuclear reactors, dynamics of heat exchanger with controlled flow, some processes in elasticity, modeling and control of a small furnace, blood pressure, cardiac regulator, behavior of sense organ, water balance, temperature regulation in human body, and a growth of a national economy [1,2].

Problems of science and technology, as well as advances in nonlinear analysis and differential geometry, led to the development of nonlinear control system theory. In an important class of nonlinear control systems, the control $u(t)$ is used as a multiplicative coefficient,

$$\dot{x}(t) = f(x(t)) + g(x(t))u(t),$$

where $f(x(t))$ and $g(x(t))$ are differentiable vector functions. They include a class of control systems in which $f(x(t)) = Ax(t)$ and $g(x(t)) = B + Nx(t)$, linear functions, so

$$\dot{x}(t) = Ax(t) + (B + Nx(t))u(t),$$

which is called a bilinear system [3]. Bilinear systems involve products of state and control, which means that the term $Ax(t)$ is a linear in state, $Bu(t)$ is a linear in control but not jointly linear in state and control in the term $Nx(t)u(t)$. In practice, due to changes in environmental conditions, aging, etc., disturbances occur during the modeling of a bilinear system. Therefore, disturbances ought to be integrated into models of bilinear systems. A disturbance signal is an unwanted input signal that affects the system's output. Actually, there will almost always be disturbances in a system. In order to minimize the effect of the disturbance signal we will need to reduce the effect of the disturbance input on the regulated output to within a prescribed level.

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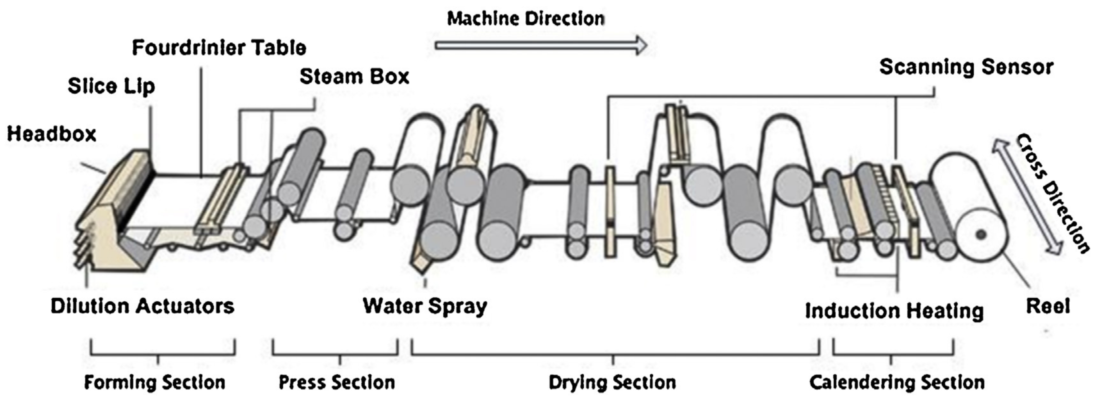

Fig. 1. Sections of the paper-making process.

The physical configuration of the paper-making process, which produces paper, is shown in Fig. 1. The thick stock from pulp workshop is pumped into a mixing box where it is mixed with chemicals and white water, then the mixture is filled into the headbox through a filter in which the dregs in stock is removed. The next step is to place the stock onto the forming wire and to remove most of the water to form paper. The paper sheet goes through the press part and dryer section to remove the remaining water and mill paper, and subsequently to accomplish the process of production.

The headbox section is the key hinge to link the pulp supply system with the sheet forming in the papermaking process. It is used to physically prepare the pulp stock before it is converted into paper by the papermaking process. The front section of the headbox, called the stock distributor, receives the pulp stock flow from one or more inlet pipes and spreads it uniformly to a width equal to the final paper width. The dryer section of the paper machine, as its name suggests, dries the paper by way of a series of internally steam heated cylinders that evaporate the moisture. So headbox section and dryer section are very important in paper-making process. In this paper will be studied robust state feedback control strategy can be used in order to improve the control quality of paper-making process.

In the literatures, the problem of controller design for naturally bilinear systems have been introduced in several approaches, e.g., a bang–bang sliding control of a class of single-input bilinear systems was introduced in [4], a self-tuning control for a class of bilinear systems was introduced in [5], The suboptimal state feedback control for single-input multi-output (SIMO) and multi-input multi-output (MIMO) bilinear system was performed in [6], a sliding mode control for a bilinear systems with time varying uncertainties was introduced in [7], an output feedback control for bilinear system has been used [8–10], design an H-infinity almost disturbance decoupling for SIMO and MIMO bilinear systems by using another form of state feedback controller for the class of MIMO bilinear system [11], a nonlinear state feedback control based on the passivity design has been introduced for a class of bilinear system [12], design of PID controller for a class bilinear plant [13], a linear state feedback controller has been used for a class of MIMO bilinear system [14], the resulting of optimal state feedback controller for MIMO bilinear systems was introduced by Ying et al. [15], and Tsai et al. [16] used state feedback for single-input single-output (SISO) bilinear system but the controller gains have been chosen, not calculated. The main goal of the present work is to design robust state feedback controller for multivariable bilinear systems with disturbance where the amplitude of the controller is bounded, unlike in state feedback linearization, and the controller gains will be calculated via LMI. The stability analysis for multivariable bilinear systems with disturbance will be studied in terms of Lyapunov function based on an LMI sufficient condition of existence. Furthermore, the proposed control scheme is designed via an $H\infty$ tracking performance, which can greatly attenuate disturbances.

This paper is organized as follows. In Section 2, problem formulation and preliminaries are provided. Section 3 presents the main results of the proposed stabilization of multivariable bilinear systems through robust state feedback control in addition to the stability analysis. In Section 4, application examples of paper-making process demonstrate the effectiveness of the proposed scheme in this paper. Finally, Section 5 concludes the paper.

2. Problem formulation and preliminaries

Consider the following class of multivariable bilinear system [2] described as:

$$\left.\begin{aligned} \dot{x}(t) &= Ax(t) + \sum_{i=1}^{m}(N_i x(t) + b_i)u_i(t) + Ew(t) \\ z(t) &= Cx(t) + Dw(t) \end{aligned}\right\} \tag{1}$$

where $x(t) \in R^n$ is the system states, $u(t) = [u_1 u_2 \ldots u_m]^T \in R^m$ is the control input, $z(t) \in R^p$ is the controlled output, and $w(t) \in R^m$ is the disturbance input. The matrices $A \in R^{n\times n}$ and it is assumed to be Hurwitz stable, $N_i \in R^{n\times n}$, $b_i \in R^n$, $E \in R^{n\times m}$, $C \in R^{p\times n}$, and $D \in R^{p\times m}$ are known with appropriate dimensions, for $i = 1, 2, \ldots, m$.

Extending the design concept of control law in [16], the state feedback controller for the class multivariable bilinear systems (1) is formulated as follows:

$$u_i(t) = \frac{\rho k_i x(t)}{\sqrt{1 + (k_i x(t))^2}} = \rho \sin \theta_i = \rho k_i x(t) \cos \theta_i \tag{2}$$