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Designing a Fuzzy Type-2 Model-Based Robust Controller for Ball and Beam System

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Abstract

In the real world an important set of existing systems are inherently non-linear and unstable and essentially require feedback control for effective and safe performance. This paper investigates the designing of an IT-2 fuzzy state feedback control for the ball and beam system. We present the system with an IT-2 fuzzy model and construct an interval fuzzy state feedback controller with an extended dissipativity performance. Finally, the existence conditions, the stability analysis and control design problem are obtained in term of convex optimization problems, which can be solved by standard software. At the end, we present the simulation results.

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Keywords: state feedback control; uncertainty; $L_2 - L_\infty$ performance; extended dissipativity performance; convex optimization;

1. Introduction

In the real world an important set of existing systems are inherently non-linear and unstable and require feedback control for effective and safe performance. Since real experiments are not possible to be brought into laboratory, using similar systems in the control laboratories has become necessary.

The ball and beam system is a known and classical dynamic system which can be founded in many undergraduate control laboratory. It is inherently non-linear and unstable, despite its simple nature, so it can be the benchmark for the control systems performance. Therefore, different methods were proposed to control this system [1, 2]. In [2, 3, 4] the authors presented input- output linearization,

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sliding mode control and adaptive control, respectively. In 2013, Li et al, published a paper in which they scribed a new controller design method for IT2 fuzzy system [5]. A considerable amount of literature has been published on parallel distributed compensation (PDC) design concept. Therefore, the fuzzy model and the fuzzy controllers share the same membership functions, which assumes that the membership functions contain no uncertainties. So far, however, there has been little discussion about uncertainty and robust control for ball and beam system. This paper deals with the problem of parameter uncertainty and using robust L_2–L_∞ state feedback controller for the ball and beam system with mismatched membership functions based on the extended dissipativity performance index [6]. Type2 fuzzy sets have the ability to reduce the effects and model them, when dealing with uncertainties [7].

The main purpose of this paper is to investigate robust control design based on the extended dissipativity performance index for the ball and beam system with parameter uncertainties and mismatched membership functions for safe performance.

The reminder of this paper is organized as follow. In section 2, we formulate the system, controller and present the IT2 fuzzy closed-loop system. Section 3, this section is concerned with the design of IT2 fuzzy state feedback controller based on the extended dissipativity performance index with L_2–L_∞ performance, finally the design method is expressed with linear matrix inequalities (LMI) terms. In this approach the asymptotic stability of the closed-loop system is proven with Lyapunov theory [7]. The simulation results for the ball and beam system are shown in section 4. Finally, the paper concludes with some brief remarks in section 5.

2. Problem Formulation

1.1. IT2 T-S Fuzzy Model

The ball and beam system is shown in fig. 1. Its dynamic equations are given as follows [5],

$$\dot{x} \quad (t),$$
$$\dot{x} \quad \left(x_1(t)x_4(t)^2 - g\sin(x_3(t))\right)$$
$$\dot{x} \quad (t)$$
$$\dot{x} \quad t). \tag{1}$$

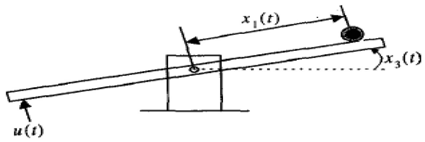

Fig. 1. A Ball and Beam System

where $x_1(t)$ is the position of the ball measured from the center of the beam, $x_2(t)$ is the velocity of the ball, $x_3(t)$ is the angle of the beam with respect to the horizontal axis, $x_4(t)$ is the angular velocity of the beam with respect to the horizontal axis; $\boldsymbol{B} = \frac{MR^2}{J_b + MR^2}$, $J_b = 2\times10^{-6}\ kgm^2$ moment of inertia of the ball about the center of the ball, $\boldsymbol{M} \in [M_{\min} \quad M_{\max}] = [0.05 \quad 0.5]kg$ is the mass of the ball, $R = 0.01m$ is the radius of the ball, $g = 9.8\ ms^{-2}$ is the acceleration due to gravity.

Equation (2) shows 4 rules of model based fuzzy system that represents the nonlinear in fig.1 [6]:

Plant Rule i: If $f_1(\boldsymbol{x}(t))$ is W_{i1} and $f_2(\boldsymbol{x}(t))$ is W_{i2}, *Then* $\dot{x} \quad \boldsymbol{x}(t) + \boldsymbol{B}_i\boldsymbol{u}(t) + \boldsymbol{D}_{1i}\boldsymbol{w}(t), \boldsymbol{i} = 1,2,3,4$ (2)

The firing interval of the i th rule is as follows [6]:

$$\tilde{t} \quad = \left[\prod_{s=1}^{2} \underline{\mu}_{w_{is}}(f_s(x(t))), \prod_{s=1}^{2} \bar{\mu}_{w_{is}}(f_s(x(t)))\right] = \left[\underline{\theta}_i(x(t)), \bar{\theta}_i(x(t))\right], \tag{3}$$

Then, the overall IT2 T-S fuzzy system for ball and beam system is represented by