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Improved exponential stability criteria of time-delay systems via weighted integral inequalities

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Abstract

In this paper, we establish new weighted integral inequalities by considering polynomials which are orthogonal in a weighted sense. These inequalities generalize some results established recently. They are applied to study exponential stability of some time-delay systems under the framework of linear matrix inequalities. Numerical tests are given to demonstrate the efficiency of the derived stability conditions.

Keywords: Exponential estimates, Time-delay systems, Linear matrix inequalities

1 Introduction

In various practical applications such as biology, economy and mechanical engineering, one frequently needs to deal with the effect of delays (see [4, 17] and the references therein). Delays can cause oscillations or bad performance in a system. This makes it necessary to study stability of time-delayed systems. In addition to stability, for some applications, it may be crucial to determine the convergence rate or the transient decaying rate of system states (see [6, 12, 18]). This is the main concern of our current study.

One of the most popular ways to study stability of time-delay system is the the Lyapunov-Krasovskii functional method, where stability criteria are given in terms of linear matrix inequalities (LMIs). This approach has been studied extensively, see [1, 10, 11, 15, 16] and the references therein. For exponential stability, interested readers can refer to [2, 3, 7, 9, 13, 14, 19]. A critical step of the Lyapunov-Krasovskii functional method which is the construction and analysis of Lyapunov functionals. The cross terms of the derivatives of these Lyapunov functionals are estimated by integral inequalities such as the Jensen, the Wirtinger inequalities and their variants. Therefore, in order to get better estimates, it is important to set up sharper integral inequalities.

Recently, some new weighted integral inequalities are derived to establish exponential stability conditions for time-delay systems in [9]. The inequalities are weighted version of the Jensen and the Wirtinger inequalities. The objective of this paper is to give the extension of the inequalities in [9]. The main idea is inspired by [15, 16] where it was pointed out that the Wirtinger inequality is derived through orthogonal polynomial approximation. It was noted that the polynomials under consideration are orthogonal in some sense. Roughly speaking, the Wirtinger inequality is derived through linear approximation. In a similar manner, the weight integral inequalities in [9] can be derived by considering linear polynomial approximation which is orthogonal in a weighted sense. With this motivation, we extend the inequalities in [9] by using quadratic polynomial approximation which provides a shaper bound for integrals involved in stability analysis. It turns out that our results cannot be proved by directly following arguments in [9]. By the new integral inequality, we give some new exponential stability criteria for time-delay systems. The results obtained improved existing ones.

2 New weighted inequalities

In the following we derive our key inequalities for stability analysis of delayed systems. For scalar functions $f(t)$, $g(t)$ on $[a, b]$, with respect to a positive weight function $w(t)$, we consider the product $\langle g, f\rangle_w = \int_a^b gfwdt$. We note that

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