PID PERFORMANCE TUNING METHODS FOR A ROBOTIC MANIPULATOR BASED ON ISS

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ABSTRACT

This paper proposes performance tuning methods for a PID controller for a robotic manipulator. The design procedures of an inverse optimal PID control method employed to assure extended disturbance input-to-state stability (ISS) are suggested. The performance tuning methods for an inverse optimal PID control are derived from the performance limitation and the bounds of the state vector. Also, the effects of proportional and integral gains are considered in evaluating the performance tuning. Finally, we show the validity of the performance tuning methods through the experiment on a robotic manipulator.

KeyWords: PID, ISS, performance tuning, performance limitation, coarse/fine tuning.

I. INTRODUCTION

PID controllers for mechanical systems, especially robotic manipulators, have overcome a number of challenges in control technology, e.g., adaptive control, backstepping control, optimal control, etc. Recently, the inverse optimality of a PID control was proved in [1] for robotic manipulators, based on the extended disturbance input-to-state stability (ISS) of PID control under some conditions for gains. Also, it was proved that the inverse optimal PID controller exists if and only if the mechanical system is extended disturbance input-to-state stable (ISS). The optimal control theory has been extended to nonlinear mechanical systems, but, the application examples given so far are restrictive and even difficult to understand. On the other hand, industries have continued to use the conventional PID controller in spite of the development of optimal control. As a matter of fact, the importance of PID control is due to the convenient applicability and clear effects of each Proportional, Integral and Derivative control. In this paper, we propose performance tuning methods of an inverse optimal PID control.

Most industrial mechanical systems can be described by Lagrangian equations of motion, and their controllers are of the conventional PID type. Under some conditions for PID gains, the globally (or semi-globally) asymptotic stability of a PID/PID set-point regulation controller for a robot system without consideration of external disturbances was proved in [2-6]. Although the PID controller has been shown in practice to be effective when applied to a robot manipulator, an asymptotic stability proof for a PID trajectory tracking control is lacking. Also, the disturbance acting on the robotic manipulators makes it difficult to prove the stability of the control system. Therefore, we need another approach to dealing with disturbances. When unknown bounded disturbances exist, such as sensor noises, perturbations and external disturbances on systems, the behavior of the system should remain bounded, and when the set of inputs, including the control, noise and disturbance, go to the zero, the behavior of system moves toward the equilibrium point. This type of stability is called input-to-state stability (ISS) [1,7-12]. ISS is helpful for understanding the effects of disturbances on system states. The basic characteristics and properties of ISS are explained in the following.

For future notations, the Euclidian norm is defined by \( |x(t)| = \sqrt{x^T(t)x(t)} \), the \( L_2 \) norm \( \|x(t)\|_{L_2} = \sqrt{\int_0^T x^T(t)x(t)dt} \), and the \( L_{\infty} \) norm \( \|x(t)\|_{L_{\infty}} = \sup_{t \geq 0} |x(t)| \).

A continuous function \( \gamma : [0, a) \to \mathbb{R} \) is said to belong to class \( K \) if it is strictly increasing and \( \gamma(0) = 0 \). It is said to belong to class \( K_\alpha \) if \( a = \infty \) and \( \gamma(x) \to \infty \) as \( x \to \infty \).

Also, a continuous function \( \beta : [0, a] \times \mathbb{R} \to \mathbb{R} \), is said