



Article

Adaptive Control Design and Stability Analysis of Robotic Manipulators

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Received: 9 October 2018; Accepted: 11 December 2018; Published: 14 December 2018



Abstract: In this paper, the author presents the adaptive control design and stability analysis of robotic manipulators based on two main approaches, i.e., Lyapunov stability theory and hyperstability theory. For the Lyapunov approach, the author presents the adaptive control of a 2-DOF (degrees of freedom) robotic manipulator. Furthermore, the adaptive control technique and Lyapunov theory are subsequently applied to the end-effector motion control and force control, as in most cases, one only considers the motion control (e.g., position control, trajectory tracking). To make the robot interact with humans or the environment, force control must be considered as well to achieve a safe working environment. For the hyperstability approach, a control system is developed through integrating a PID (proportional–integral–derivative) control system and a model reference adaptive control (MRAC) system, and also the convergent behavior and characteristics under the situation of the PID system, model reference adaptive control system, and PID+MRAC control system are compared.

Keywords: adaptive control; stability; Lyapunov; hyperstability; robotic manipulator

1. Introduction

Robotic mechanisms have been maturely employed in manufacturing industries [1–4]. In current robotic based manufacturing industries (e.g., in manufacturing assembly lines), robots are designed to work independently. In the situation where rapid changes in assembled products is required, traditional assembly robots are not capable to adapt to the rapid changes in assembled products. Robots working with humans is one of the effective solutions to the above situation. To make robots work with human operators, the most important issue is that robots must safely respond to contact forces while performing work. For example, a robot needs to stop or slow down when touched by a human operator, a robot must limit the amount of force it exerts while performing task, and a robot can be pushed out of the way by contact if necessary.

Furthermore, when a robot manipulator end-effector grasps an object to conduct work, it will change the dynamics of the robotic manipulator since the mass and initial properties of the grasped object may be unknown. Under this situation, traditional controls (e.g., PD (proportional–derivative) control) are not sufficient anymore. During the process of robotic mechanisms, the end-effector takes different weights of loads, usually the joint's output fluctuates along with time, and this phenomenon can deteriorate the end-effector's positioning accuracy. Rather, one approach to handle changing conditions is the adaptive control technique. In this paper, the adaptive control design and stability analysis for robotic manipulators based on two main approaches, i.e., Lyapunov stability theory and hyperstability theory, are presented. Regarding the adaptive control design and stability analysis for robotic manipulators based on Lyapunov stability theory, in most cases, one only considers the motion control. When a robot interacts with humans or the environment, force control also must be considered to achieve a safe working environment. For example, large force may damage the objects being manipulated; small force may not achieve the desired goal. The right amount of force is crucial for the human-robot interaction. Subsequently, the adaptive control technique is also applied to the

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