

Survey

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Control of distributed-parameter systems using normal forms: An introduction

Abstract: This paper gives an overview of the control of distributed-parameter systems using normal forms. Considering linear controllable PDE-ODE systems of hyperbolic type, two methods derive tracking controllers by mapping the systems into a form that is advantageous for the control design, analogous to the finite-dimensional case. A flatness-based controller makes use of the hyperbolic controller canonical form that follows from a parametrization of the system's solutions. A backstepping design exploits the strict-feedback form of the system to recursively stabilize and transform the subsystems.

Keywords: distributed-parameter systems, state feedback, backstepping, flatness, canonical forms

1 Introduction

In control theory, a normal or canonical form usually refers to a special state-space representation of a dynamical system that is well-suited for a certain analysis or synthesis purpose. Thereby, the label canonical is usually used if a form is unique. The basic idea of a controller design using normal forms is sketched in Figure 1. For linear finite-dimensional single-input single-output (SISO) systems, the pioneering work [20] introduced the controller canonical form (CCF) and the observer canonical form (OCF) that are also sometimes called the controllable and observable canonical form, respectively. While any observable system can be mapped into OCF, the CCF

$$\dot{\eta} = \begin{bmatrix} 0 & 1 & 0 & \dots & 0 \\ \vdots & \ddots & \ddots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \ddots & 0 \\ 0 & \dots & \dots & 0 & 1 \\ -a_0 & -a_1 & \dots & \dots & -a_{n-1} \end{bmatrix} \eta + \begin{bmatrix} 0 \\ \vdots \\ \vdots \\ 0 \\ 1 \end{bmatrix} u \quad (1)$$

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exists for any controllable system. It is well known that the design of a stabilizing state feedback for (1) is straightforward as the characteristic coefficients a_i , $i = 0, \dots, n-1$, are simply replaced by some desired ones of a stable closed-loop system (e.g. [28]). This simplicity motivates the use of normal forms for a design. As illustrated in Figure 1, instead of a potentially very involved synthesis based on the original representation, a system is first mapped into, e.g., CCF, with a stabilizing feedback of the normal form state implied by the obtained simple system structure. Together with the inverse state transformation this results in the sought feedback of the original state. This design strategy using normal forms is not limited to linear finite-dimensional systems.

The nonlinear counterpart of (1) also involves a chain of integrators, with a nonlinear function in the last differential equation (e.g. [39]). As in the linear setting, the existence of such a nonlinear CCF is closely related to the controllability of the system. Flatness or more precisely differential flatness (see, e.g., [14, 23, 27]) is a system property that can be interpreted as one possible extension of the notion of controllability to nonlinear systems. If a system is flat, there exists a (fictitious) flat output that allows to express all system variables – in particular the state and the input – in terms of the flat output and a finite number of its time derivatives. Not only is this flatness-based parametrization known to allow for an easy trajectory planning and feedforward design, but the flat output and its derivatives also form a nonlinear CCF state. Consequently, the controller synthesis for flat systems is straightforward. For example, all nonlinear SISO systems in strict-feedback form

$$\dot{q}_1 = f_1(q_1) + g_1(q_1)u_2 \quad (2a)$$

$$\dot{q}_2 = f_2(q_1, q_2) + g_2(q_1, q_2)u_3 \quad (2b)$$

$$\vdots$$

$$\dot{q}_n = f_n(q_1, \dots, q_n) + g_n(q_1, \dots, q_n)u \quad (2c)$$

(see, e.g., [21]) are flat due to their structure, with the differential equation for $q_i(t)$, $i = 1, \dots, n$, only depending on $u_1(t), \dots, u_{i+1}(t)$ (with $u_{n+1}(t) = u(t)$). Thus, $q_1(t)$ constitutes a flat output. The well-known backstepping

Distributed Parameter Control Systems Trends And Applications

Ensheng Dong



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Table of Contents Distributed Parameter Control Systems Trends And Applications

1. Understanding the eBook Distributed Parameter Control Systems Trends And Applications
 - The Rise of Digital Reading Distributed Parameter Control Systems Trends And Applications
 - Advantages of eBooks Over Traditional Books
2. Identifying Distributed Parameter Control Systems Trends And Applications
 - Exploring Different Genres
 - Considering Fiction vs. Non-Fiction
 - Determining Your Reading Goals
3. Choosing the Right eBook Platform
 - Popular eBook Platforms
 - Features to Look for in an Distributed Parameter Control Systems Trends And Applications
 - User-Friendly Interface
4. Exploring eBook Recommendations from Distributed Parameter Control Systems Trends And Applications
 - Personalized Recommendations
 - Distributed Parameter Control Systems Trends And Applications User Reviews and Ratings
 - Distributed Parameter Control Systems Trends And Applications and Bestseller Lists
5. Accessing Distributed Parameter Control Systems Trends And Applications Free and Paid eBooks
 - Distributed Parameter Control Systems Trends And Applications Public Domain eBooks
 - Distributed Parameter Control Systems Trends And Applications eBook Subscription Services
 - Distributed Parameter Control Systems Trends And Applications Budget-Friendly Options
6. Navigating Distributed Parameter Control Systems Trends And Applications eBook Formats
 - ePub, PDF, MOBI, and More
 - Distributed Parameter Control Systems Trends And Applications Compatibility with Devices
 - Distributed Parameter Control Systems Trends And Applications Enhanced eBook Features
7. Enhancing Your Reading Experience

- Adjustable Fonts and Text Sizes of Distributed Parameter Control Systems Trends And Applications
 - Highlighting and Note-Taking Distributed Parameter Control Systems Trends And Applications
 - Interactive Elements Distributed Parameter Control Systems Trends And Applications
8. Staying Engaged with Distributed Parameter Control Systems Trends And Applications
 - Joining Online Reading Communities
 - Participating in Virtual Book Clubs
 - Following Authors and Publishers Distributed Parameter Control Systems Trends And Applications
 9. Balancing eBooks and Physical Books Distributed Parameter Control Systems Trends And Applications
 - Benefits of a Digital Library
 - Creating a Diverse Reading Collection Distributed Parameter Control Systems Trends And Applications
 10. Overcoming Reading Challenges
 - Dealing with Digital Eye Strain
 - Minimizing Distractions
 - Managing Screen Time
 11. Cultivating a Reading Routine Distributed Parameter Control Systems Trends And Applications
 - Setting Reading Goals Distributed Parameter Control Systems Trends And Applications
 - Carving Out Dedicated Reading Time
 12. Sourcing Reliable Information of Distributed Parameter Control Systems Trends And Applications
 - Fact-Checking eBook Content of Distributed Parameter Control Systems Trends And Applications
 - Distinguishing Credible Sources
 13. Promoting Lifelong Learning
 - Utilizing eBooks for Skill Development
 - Exploring Educational eBooks
 14. Embracing eBook Trends
 - Integration of Multimedia Elements
 - Interactive and Gamified eBooks

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