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A Quadratic Constraint Approach to Model Predictive Control of Interconnected Systems

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Preface

The attraction of achieving higher efficiency and reliability for industrial plants and networked systems has created new research opportunities in the control and optimisation field. Among different design methods, the model predictive control (MPC) strategies, first developed for the petroleum refining industry, have proved to be effective in many applications. Originally found a widespread use in the stand-alone sites, the non-centralised adaption such as distributed and decentralised MPCs have been progressing towards more heterogeneous architectures that are able to cope with system complexities and variations in application domains.

This book presents a stabilising method for the control of interconnected systems having mixed connection configurations with distributed and decentralised model predictive control schemes. The novel notions of asymptotically positive realness constraint (APRC) and quadratic dissipativity constraint (QDC) are introduced as a fundamentally constituent part of this book. In both constraints, the function of inputs and outputs in the form of a supply rate, or a 'supply power', is quadratic. From the communication and information perspective, the quadratic constraint packs two pieces of information, the control and state vectors, into one variable, before carrying to different locations, and then unpacks them for use with the local control algorithm. The employment of quadratic constraints in two distinct approaches, segregation from and integration into the control algorithms, for the constrained stabilisation of interconnected systems is another contribution of this book.

Solutions for linear systems are given in distributed and decentralised strategies whereby the communication between subsystems is either fully connected, partially connected or totally disconnected. The interconnected systems and their distributed computerised-control platforms are considered within the realm of a cyber-physical system consisting of the physical connections between subsystems and the communication links between local computing processors. Within the auspice of the integrated construction method, the distributed and decentralised MPC strategies deal with the communication links from the cyber-connection side—the subsystems are wholly or partially connected in a distributed MPC scheme while being totally disconnected in a decentralised MPC.

By having the control inputs entirely or partially decoupled between subsystems, and no additional constraints imposed on the interactive variables, rather than the coupling constraint itself, the proposed approaches outreach various types of networked systems and applications. The effects of coupling delays and device networks are also resolved in part of the development. For parallelised connections that emulate parallel redundant structures and have unknown splitting ratios, a fully decentralised control strategy is developed as an alternative to the hybrid system approach. For the semi-automatic control systems, involved with both closed-loop and human-in-the-loop regulatory controls, the stability-guaranteed method of decentralised stabilising agents, that are interoperable with different control algorithms, is germinated and implemented for each single subsystem.

For nonlinear input-affine systems, the extended output vector including the vector field and the state vector are introduced such that the dissipativity criterion can be rendered in linear matrix inequalities. The compound vector can be viewed as manifest variables in the beviourial framework for dynamical systems. From the perspective of the dissipative system theory, both the storage function and supply rate with the extended output vectors are parameterised to avoid any conservativeness that may incur to the stabilisation of nonlinear systems.

In this book, MPC is formulated with state-space models having a standardised cost function. The stability constraint here is a constraint imposed on the current-time control vector, independently to the MPC objective function. For interconnected systems, the terminal constraint computations are formidable when dealing with subsystems having dissimilar dynamics whose settling times are heterogeneous. The quadratic constraint approach resolves this difficulty by having a constraint on the current-time control vector. The state constraint and recursive feasibility are, nevertheless, not included in this book.

An extension to new applications with the Internet of Things (IoT) is also presented with some dependable control schemes in which multiple controllers and sensors are cross-connected via the IoT communication network to ensure the duty-standby architecture for achieving quantitatively higher reliability of cyber-physical systems.

A broad range of applications in the process and manufacturing industries, networked robotics, networked control systems and network-centric systems such as power systems, telecommunication networks and chemical processes will benefit from the approaches in this book. Illustrative examples of networked interconnected systems are provided with numerical simulations in MATLAB environment. Specifically, a power system having four control areas, a dependable controller for cyber-physical systems and some other numerical examples are implemented with the distributed and decentralised MPC strategies employing the quadratic constraint approach to demonstrate the theoretical appraisals.

The developments are presented in seven chapters. This book starts with an introduction to the quadratic constraint in the time domain with a different perspective, as stated in Chap. 1. Here, the differences between this closed-loop perspective on the dissipation-based constraint and the other open-loop dissipative system approaches in the well-known interconnection stability conditions with passivity and small-gain theorems will be highlighted. A brief review on the MPC applications and the stabilising methods for the previously developed distributed MPC strategies is also given in the first chapter. Chapter 2 is dedicated to the quadratic constraints and their applications to the decentralised MPC of interconnected systems as the enforced attractivity constraints. In the next chapter, the attractivity conditions for the complex interconnected systems that have parallelised connections with unknown splitting ratios are presented, Chap. 3. An alternative constructive method of stabilising agents with the QDC is then delineated following in Chap. 4. Chapter 5 outlines a deterministic approach to the data lost processes with the presented dissipation-based quadratic constraints. A virtual perturbed cooperative-state feedback (PSF) strategy will be presented in the second part of this chapter. The available communication network in a cyber-physical system is capitalised on for improving the control performance with the PSF strategy. The developments for interconnected systems having a coupling delay element with the accumulative quadratic constraints are subsequently provided in Chap. 6. Chapter 7 is dedicated to the QDC application to the dependable control systems.

The general dissipativity constraint (GDC) method for the control design and synthesis of multi-variable systems in the discrete-time domain is presented in Appendix A. APRC and QDC with quadratic supply functions are the two special cases of the GDC. The dissipation-based constraints with a general supply function and the stability with a relaxed non-monotonic Lyapunov function and the input-to-power-and-state stabilisability (IpSS) are presented in this appendix. The GDC method for stabilising the interconnected systems with distributed, decentralised and dependable control architectures is well suited to the modern cyber-physical systems incorporating scalable and flexible communication networks. With emerging technologies in the Internet of Things (IoT) and cloud computing, the new architecture and algorithms will provide the tractability for implementations in a connected and 'smart' environment, yet help achieve the required reliability and continuity of the operational systems. The well-known MPC algorithms that employ plant models in the future state prediction for computing the control moves with convex optimisations have been found agile for deploying with cyber-physical systems.

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Contents

List of Figures