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978-0-521-76505-3 — Handbook of Hybrid Systems Control
Edited by Jan Lunze, Françoise Lamnabhi-Lagarrigue
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HANDBOOK OF HYBRID SYSTEMS CONTROL

Setting out core theory and reviewing a range of new methods, theoretical problems, and applications, this handbook shows how hybrid dynamical systems can be modeled and understood. Sixty expert authors involved in the recent research activities and industrial application studies provide practical insights on topics ranging from the theoretical investigations over computer-aided design and verification tools to applications in several domains.

Structured into three parts, the book opens with a thorough introduction to hybrid systems theory, illustrating new dynamical phenomena through numerous examples and showing novel modeling, analysis, and design techniques that have been elaborated recently for this new system class. Part II then provides a survey of key tools and tool integration activities. Finally, Part III is dedicated to applications, implementation issues, and system integration, considering applications to energy management, the process industry, automotive systems, and digital networks.

Three running examples are referred to throughout the book, together with numerous illustrations, helping both researchers and industry professionals to understand complex theory, recognize problems, and find appropriate solutions.

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Handbook of Hybrid Systems Control

Theory, Tools, Applications

Edited by

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Preface

Hybrid systems are dynamical systems that consist of components with continuous and discrete behavior. Modeling, analysis, and design of such systems raise severe methodological questions, because they necessitate the combination of continuous-variable system descriptions like differential and difference equations with discrete-event models like automata or Petri nets. Consequently, hybrid systems methodology is based on the principles and results of the theories of continuous and discrete systems, which, until recently, have been elaborated separately, with contributions coming from different disciplines, such as control theory, computer science, and mathematics.

This handbook reviews the new phenomena and theoretical problems brought about by the combination of continuous and discrete dynamics and surveys the main approaches, methods, and results that have been obtained during the last decade of research in this field. It is structured into three main parts:

- *Part I: Modeling, analysis, and control design methods*: The first part gives a thorough introduction to hybrid systems theory. The material is classified by the modeling approaches used to represent hybrid systems in a form that is convenient for analysis and control design. Hybrid automata and switched systems are well-studied system classes, which are extensively described, but other approaches like mixed logical dynamical systems, complementarity systems, quantized systems, and stochastic hybrid systems are also explained.

- *Part II: Tools*: The second part is concerned with computer-aided systems analysis, control design, and verification. After a survey of the variety of relevant tools, selected tools are described in more detail. This part concludes with a presentation of current tool integration activities.

- *Part III: Applications*: The third part is devoted to applications, implementation issues, and system integration. Concentrating on energy management, industrial control, automotive control, and networked control systems, important application domains are considered.

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This bridge from the theory over the tools towards applications shows the advances made in hybrid systems theory over the last 10 years as well as the main gaps that have to be closed in the near future to improve the multidisciplinary design of modern technological systems. Due to its restricted size, the handbook has to concentrate on the most successful lines of current research and on the fields of applications where hybrid systems theory has facilitated significant progress.

This handbook is considerably different from the increasing number of publications that have recently appeared. Monographs and paper collections concerning specific types of hybrid systems focus on the theoretical background and place little importance on applications. The handbook fills the current lack of a basic introduction to hybrid systems from a control perspective, gives a survey of the field as a whole, and indicates the importance of recent theoretical developments using examples of applications.

Readership and structure The handbook has been written for all those who require an overview of the theory of hybrid systems. Potential readers are researchers in academia and industrial professionals who are engaged in the development of control systems for complex applications, as well as graduate and PhD students. They are assumed to be familiar with dynamical systems theory and should have some knowledge of both continuous and discrete-event systems.

For this readership, the handbook provides basic introductory information, detailed descriptions of selected topics, and extensive references to the rapidly growing literature. In each chapter, the first section gives a **broad introduction** to the subject followed by sections that provide a more detailed development of important subtopics. Three **running examples** are used for the illustration of the methods and tools described in Parts I and II. Each chapter ends with **bibliographical notes**.

There is no uniform theory of hybrid systems yet, but the development of this field has been guided by different modeling approaches, which have in turn led to corresponding analysis and design methods. Although some relations among these approaches have been established, each approach is particularly suitable for its specific class of hybrid systems. The handbook, in particular Part I, is structured accordingly. As hybrid automata and piecewise affine systems have gained particular interest in research, a whole chapter is devoted to each of them, whereas further modeling ideas are summarized in additional theory chapters.

In addition, the field does not yet have a uniform terminology and notation, but instead has a mixture of notions and symbols with their origins in control theory and computer science. An important aim of this handbook is to bring them closer together.

Hybrid systems research, training, and innovation This handbook is a result of four years of cooperation within the FP6 *Network of Excellence HYCON*– "Hybrid Control: Taming Heterogeneity and Complexity of Networked Embedded Systems" (EU project IST-2004-511368, http://www.ist-hycon.org), gathering 26 partners from European academic institutions, industry, and private and public research agencies. It summarizes the research interests and common expertise of more

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than 60 authors in this network and gives, in this sense, a *European* view on the field with emphasis on the research results of the participating institutions and groups. All sections are co-authored by researchers who have contributed to the corresponding topic during recent years. They are mentioned in alphabetic order with the responsible author first.

The Network of Excellence will end in the spring of 2009. The goals of the HYCON Network include the coordination of the efforts of the European scientific community through the creation of a common research program on the control of networked embedded systems, the creation of a research infrastructure shared among the members of the network in order to facilitate long-term scientific collaborations, and the implemention of new working methodologies and improving the research efficiency by several coordination, education, and mobility programs. A further important aspect of HYCON is the collaboration of academic research institutions with industrial partners in the fields of process and energy control, automotive applications, and communication networks, the result of which is presented in Part III of this handbook.

As a tangible and durable result of HYCON, the **European Embedded Control Institute** (EECI) was incorporated (under the French Association Law 1901) in 2006 to provide a sustainable structure to support the research community in this field (http://www.eeci-institute.eu). EECI is rapidly becoming a worldwide leading focal point in hybrid systems research and is helping to attract the brightest minds in the field to the European research area. After the HYCON Network of Excellence has finished, the EECI will remain and will continue to attract young and senior researchers and practitioners, thus yielding strong long-term collaborations among the participating members. EECI is currently located in Gif-sur-Yvette, France, and has a networked embedded control laboratory in L'Aquila, Italy.

Acknowledgement Several organizations and persons have helped to make this handbook idea a reality. The funding of the HYCON Network of Excellence by the European Union created the organizational environment. Mr. Daniel Lehmann has structured the writing process by creating guidelines and templates and by retaining the communication among the co-authors. Ms. Andrea Marschall has drawn and redrawn many figures and Ms. Hannelore Hupp has helped to give the book a uniform layout.

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Notation

The symbols are chosen according to the following conventions. Scalar values or signals are denoted by lower-case letters such as x, a or t, vectors by boldface letters such as $\boldsymbol{x}$ or $\boldsymbol{y}$ and matrices by boldface upper-case letters such as $\boldsymbol{A}$, $\boldsymbol{B}$. Accordingly, the elements $x_1, \ldots, x_n$ of a vector $\boldsymbol{x}$ or $a_{11}, a_{12}, \ldots, a_{mn}$ of a matrix $\boldsymbol{A}$ are represented by italics. Sets are symbolized by calligraphic letters such as $\mathcal{F}$ and $\mathcal{Z}$.

Unless the current literature uses other notations, q is the discrete state and $\boldsymbol{x}$ the continuous state of a hybrid system. $\boldsymbol{u}$ and $\boldsymbol{y}$ denote the continuous input or continuous output, respectively, of the system.

The inequality $\boldsymbol{P} > 0$ is interpreted in two different ways, which is explicitly mentioned. In connection with optimal control or linear matrix inequalities, it states that the matrix $\boldsymbol{P}$ is positive definite. Alternatively, the sign $>$ has to be interpreted as an elementwise relation saying that all elements of the matrix $\boldsymbol{P}$ are positive ($p_{ij} > 0$ for all i, j).

Book homepage See book homepage at http://www.rub.de/atp → Books for further information and computer programs for the animation of important hybrid systems phenomena.

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