Springer Tracts in Advanced Robotics

Volume 60

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Virtual Decomposition Control

Toward Hyper Degrees of Freedom Robots

Springer

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ISBN 978-3-642-10723-8 e-ISBN 978-3-642-10724-5

DOI 10.1007/978-3-642-10724-5

Springer Tracts in Advanced Robotics ISSN 1610-7438

Library of Congress Control Number: 2009944183

Typeset & Cover Design: Scientific Publishing Services Pvt. Ltd., Chennai, India.

Printed on acid-free paper

5 4 3 2 1 0

springer.com

STAR (Springer Tracts in Advanced Robotics) has been promoted under the auspices of EURON (European Robotics Research Network)

European ROBOTICS Research Network EURON

Foreword

By the dawn of the new millennium, robotics has undergone a major transformation in scope and dimensions. This expansion has been brought about by the maturity of the field and the advances in its related technologies. From a largely dominant industrial focus, robotics has been rapidly expanding into the challenges of the human world. The new generation of robots is expected to safely and dependably co-habitat with humans in homes, workplaces, and communities, providing support in services, entertainment, education, healthcare, manufacturing, and assistance.

Beyond its impact on physical robots, the body of knowledge robotics has produced is revealing a much wider range of applications reaching across diverse research areas and scientific disciplines, such as: biomechanics, haptics, neurosciences, virtual simulation, animation, surgery, and sensor networks among others. In return, the challenges of the new emerging areas are proving an abundant source of stimulation and insights for the field of robotics. It is indeed at the intersection of disciplines that the most striking advances happen.

The goal of the series of *Springer Tracts in Advanced Robotics (STAR)* is to bring, in a timely fashion, the latest advances and developments in robotics on the basis of their significance and quality. It is our hope that the wider dissemination of research developments will stimulate more exchanges and collaborations among the research community and contribute to further advancement of this rapidly growing field.

The monograph written by Wen-Hong Zhu is the outcome of several years of work by the author, stemming from his doctoral thesis. The main contribution of this book is the presentation of the so-called Virtual Decomposition Control (VDC) to dynamics and control of complex robotic systems. The pursued approach can be adopted for a wide range of robots, including the actuation system. Constrained and multi-arm robots, space robots, humanoid robots, teleoperated robots, flexible robots and more generally hyper degree-of-freedom modular systems can be keenly dealt with VDC while ensuring their stability. Remarkably, the theoretical analysis is supported by several useful examples and practical case studies.

This volume is a very fine addition to our STAR series!

Naples, Italy
September 2009

Bruno Siciliano
STAR Editor

This book is dedicated to

George Vukovich
Septimiu E. (Tim) Salcudean
Joris De Schutter
Zeungnam Bien
Zhongjun Zhang
Yugeng Xi
Huitang Chen

for their academic inspiration, essential help, and financial support

Preface

Robot control, a subject aimed at making robots behave as desired, has been extensively developed for more than two decades. Among many books being published on this subject, a common feature is to treat a robot as a single system that is to be controlled by a variety of control algorithms depending on different scenarios and control objectives. However, when a robot becomes more complex and its degrees of freedom of motion increase substantially, the needed control computation can easily go beyond the scope a modern computer can handle within a pre-specified sampling period. A solution is to base the control on subsystem dynamics.

This book entitled *Virtual Decomposition Control* (VDC) is the first book that talks about subsystem based control of robots without compromising control performances. The VDC approach uses subsystem dynamics to conduct control computation, while rigorously guaranteeing the stability of the entire robot without imposing additional approximations. Unlike decentralized control, the dynamic interactions among subsystems are mathematically handled through the definition of *virtual power flows.* A unique property with this novel approach is that the sum of all *virtual power flows* will be or must be zero at the end.

This book comprises two parts with fourteen chapters. The first part comprised of Chapters 1 to 4 presents all theoretical contents necessarily needed to conduct the VDC for any complex robot. Specifically, Chapter 1 gives an introductory description about the background that motivates the creation of this novel control approach. Chapter 2 collects all mathematical foundations to be used later on by the VDC. Most importantly, the concept of the *virtual stability* is introduced. The unique characteristic of the *virtual stability* is the inclusion of the *virtual power flows* in the time derivative of the *non-negative accompanying function* assigned to each subsystem. The importance of defining the *virtual stability* lies in the fact that the (L_2 and L_∞) stability of the entire complex robot can be guaranteed as long as *every* subsystem combined with its respective control equations qualifies to be *virtually stable.* Chapter 3 takes a two degrees of freedom planar robot as a simple example to demonstrate how the VDC works. Finally in Chapter 4, a general formulation of the VDC when being applied to a generalized complex robot is given. This chapter ends with discussions on its relationships to the passivity theory and to PID control.

The second part comprised of Chapters 5 to 14 is dedicated to specific applications. Chapter 5 is a *must-read* chapter that applies the VDC to a class of the most popular six-joint robot manipulators in both free motion and constrained motion. Three joint control modes suitable for different electronic control interfaces are presented. Starting from Chapter 6, each chapter becomes independent.

Prospective readers are suggested to read Chapters 1 to 3 and 5 to fully understand the basic concepts of the VDC approach. From this point, readers might have several options. A reader might decide to go back to Chapter 4, if a general formulation of the VDC is a concern. Chapter 6 is recommended for readers who are interested in motor-transmission mechanisms including the commonly used harmonic drives. Readers working on hydraulic robots might find it interesting to go to Chapter 7. Chapter 8 is particularly dedicated to the coordinated control of multiple robot manipulators holding a common object. Readers in the space robotics society might have interest in Chapter 9. Furthermore, a possible application of the VDC to humanoid robots is initialized in Chapter 10. Readers interested in force-reflected bilateral teleoperation are suggested to examine Chapter 11 for an alternative solution based on adaptive control to automatically accommodate the system uncertainties, leading to superior operational performances. Chapter 12 applies the modularity of the VDC to modular robot manipulators, aimed at giving the modular robot manipulators the same dynamics based control performances as these integrated robot manipulators. Readers who have been working on control of flexible link robots are encouraged to investigate Chapter 13 in which the VDC is extended to distributed parameter systems. Finally in Chapter 14, the extension of the VDC to a current control problem of electrical circuits is briefly discussed for the first time, making use of the duality between mechanical and electrical systems.

The author is grateful to Dr. George Vukovich for his invaluable helps and efforts on editing a draft version of the first four chapters to enhance the readability of this book. His comments on the presentation certainly help improve the quality of the book further. The author would also like to thank Dr. Bruno Siciliano, STAR Editor, for his rigorous handling of the review process, leading to the acceptance of the book proposal. Finally, special thanks are due to Dr. Thomas Ditzinger, Senior Editor of Engineering, Springer-Verlag, for his consistent support of this book project right from the beginning, seeing it to the successful completion with great patience.

Brossard, Québec
Canada

Wen-Hong Zhu
September 2009

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