Dynamics of Tree-Type Robotic Systems

International Series on
INTELLIGENT SYSTEMS, CONTROL AND AUTOMATION:
SCIENCE AND ENGINEERING

VOLUME 62

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Dynamics of Tree-Type Robotic Systems

Springer

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ISBN 978-94-007-5005-0 ISBN 978-94-007-5006-7 (eBook)
DOI 10.1007/978-94-007-5006-7
Springer Dordrecht Heidelberg New York London

Library of Congress Control Number: 2012954613

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Preface

Robots have evolved since birth of first industrial robot in 1961. Rapid industrialization, automation, high rate of production and maximizing human comfort in the modern times have necessitated various multifaceted applications of robots, which are required to perform complex tasks. As a result, multiple-chain tree-type robotic systems such as multi-fingered robotic arms, legged vehicles, humanoid robots, etc. have emerged. Successful as well as fast operation of such robots calls for systematic, efficient, and as far as possible generic computational framework to predict dynamic behavior. The framework should be useful in robot operation, trajectory planning, simulation and control. Driven by this motivation, an attempt has been made in this book to present a modular framework for dynamic modeling and analysis of tree-type robotic systems.

Robots having general tree-type architectures have been considered first. The concept of kinematic modules, where each module is essentially a serial-chain system, has been introduced. Macroscopically, module may be viewed similar to a link in the serial chain system. Next, module-level decoupled form of velocity transformation matrix, i.e., Decoupled Natural Orthogonal Complement matrices (DeNOC), is obtained by following the recursive relationships between any two adjoining modules. The constrained equations of motion are then obtained by using the module-level DeNOC matrices. Modular framework offers many advantages. For example, it makes the kinematic as well as dynamic representations compact, allows module-level expressions for various entities, and enables repeated use of module-level computations. A novel concept of Euler-Angle-Joints (EAJs) is also introduced to represent a spherical joint, which allows for unified representation of multiple-DOF joints that commonly appear in spatial systems.

Following the DeNOC-based approach, it is possible to obtain module-level analytical expression of the Generalized Inertia Matrix (GIM), which is used for module-level decomposition of the GIM. The decomposition allows one to invert the GIM analytically. The analytical inversion provides recursive forward dynamics algorithm, an insight into the associated dynamics, and help in predicting any inconsistency in the dynamic behavior of a robot.

Empowered with the modular framework, studies of dynamic behavior of fixed-base as well as floating-base robotic systems have been taken up. Initially, motion and force analyses of several fixed-base tree-type systems, e.g., a robotic gripper, biped, and hyper-degrees-of-freedom (hyper-DOF) system, are presented. This is followed by the approach where the legged robots are modeled as a floating-base with several branches (limbs or legs) emanating from the floating-base. Such approach provides more realistic modeling of the legged robots. In order to show the effectiveness of the modeling approach, legged robots are simulated under model-based control laws (e.g., computed-torque and feedforward). Computational complexities in terms of operation counts and CPU times are also reported to show that the methodology presented performs much better than many commonly used methodologies reported in literature. The efficacy of the approach increases with the complexity, primarily with total number of links and number of multiple-DOF joints in the system.

In summary, the book addresses dynamic modeling methodology and analyses of tree-type robotic systems. Such analyses are required to visualize the motion of a system without really building it. The book contains novelty in the form of treatment of the tree-type systems using concept of kinematic modules, unified representation of the multiple-degrees-of-freedom joints, efficient recursive dynamics algorithms, and detailed dynamic analyses of several legged robots.

This book is useful for teaching graduate-level (Master's and Ph.D.) courses specialized in Robot Dynamics and Legged robots. This book will also help researchers and practicing engineers in virtual testing, trajectory planning, designing and controlling complex robotic systems. In order to help the readers to quickly analyze their systems the ReDySim (Recursive Dynamic Simulator) developed based on the methodologies presented in this book is made freely available through the website http://www.redysim.co.nr/book.html.

Units and Notation

The international System of Units (SI) is used throughout this book. The boldface Latin/Greek letters in lower and upper cases denote vectors and matrices, respectively, whereas light face Latin/Greek letters in lower case with italic font denote scalars. In the case of any deviation in the above definitions, an entity is defined as soon as it appears in the text. Moreover, symbol '–' over an entity signifies that it is associated with a kinematic module of the tree-type systems under study.

Acknowledgments

We would like to thank all who have directly or indirectly helped in the preparation of this book. Special thanks are due to Indian Institute of Technology (IIT) Delhi where the first author did his Ph.D. We also thank people of Mechatronics Laboratory at IIT Delhi, and others with whom we had many discussions about life and education that may have influenced the presentation of this book indirectly. Special thanks are also due to our respective family members, Kruti and Arjav (with Suril Vijaykumar Shah), Bulu and Esha (with Subir Kumar Saha), and Mitali and Anabil (with Jayanta Kumar Dutt) for their patience and understanding while this book was under preparation. In addition, we express our sincere gratitude to Ms. Nathalie Jacobs of Springer Netherlands and anonymous reviewers for readily accepting the book for publication.

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