Springer Tracts in Advanced Robotics

Volume 8

Editors: Bruno Siciliano · Oussama Khatib · Frans Groen

Springer

Berlin
Heidelberg
New York
Hong Kong
London
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Paris
Tokyo

J. Baeten · J. De Schutter

Integrated Visual Servoing and Force Control

The Task Frame Approach

With 115 Figures

Springer

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

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ISSN 1610-7438

ISBN 3-540-40475-9 Springer-Verlag Berlin Heidelberg New York

Library of Congress Cataloging-in-Publication Data
Baeten, J. (Johan), 1968-
Integrated visual servoing and force control : the task frame approach / J. Baeten, J. De Schutter.
p. cm. -- (Springer tracts in advanced robotics ; 8)
Includes bibliographical references and index.
ISBN 3-540-40475-9 (cloth : alk. paper)
1. Robotics--Control systems. 2. Servomechanisms. I. Schutter, J. de (Joris) II. Title. III. Series.

TJ211.35.B34 2003
629.8'92--dc22 2003059533

Springer-Verlag Berlin Heidelberg New York
a member of BertelsmannSpringer Science + Business Media GmbH

http://www.springer.de

Typesetting: Digital data supplied by author.
Data-conversion and production: PTP-Berlin Protago-TeX-Production GmbH, Berlin
Cover-Design: design & production GmbH, Heidelberg
Printed on acid-free paper 62/3020Yu - 5 4 3 2 1 0

Foreword

At the dawn of the new millennium, robotics is undergoing a major transformation in scope and dimension. From a largely dominant industrial focus, robotics is rapidly expanding into the challenges of unstructured environments. Interacting with, assisting, serving, and exploring with humans, the emerging robots will increasingly touch people and their lives.

The goal of the new 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 Johan Baeten and Joris De Schutter builds upon an important paradigm for sensor-based robotics inspired by human natural behaviours: see and touch! An integrated vision/force approach is developed which clearly bridges the existing gap between visual and force feedback, up to the point of keenly combining the advantages of both sensors while overcoming their individual drawbacks. Its potential impact on the performance of the next generation of robots is starting to be recognized by major manufacturers world-wide. To this regard, the unique feature of the work lies in its comprehensive treatment of the problem from the theoretical development of the various schemes down to the real-time implementation of interaction control algorithms on an industrial robot.

Remarkably, the doctoral thesis at the basis of this monograph was a finalist for the Second EURON Georges Giralt PhD Award devoted to the best PhD thesis in Robotics in Europe. A fine addition to the series!

Naples, Italy
May 2003

Bruno Siciliano
STAR Editor

Preface

Sight and touch are two elementary, but highly complementary, senses. They contribute to the unique abilities of one of the most versatile manipulators of nature: man. Projecting these sensing abilities to robotics fans our imagination of the robot as an image of human kind. Whenever one of these senses is missing, we might find ourself in the dark or feel isolated. Is this what a 'sensorless' robot must feel like? Then, let him see and let him feel!

Early research on vision and force sensing created two separate interest groups: the visual servoing community and the force control community. Due to the very complementary nature of vision and force, both groups developed very specific ways in tackling sensor based robotics. Initially, this work was situated in some kind of niche, with almost no references to integrated vision/force approaches in robotics. Clearly, the lack of a common basis for integrated vision and force control prevented the bridging of both worlds. Bridging this gap is the aim of this book. The framework presented in this book provides and answer to the recently emerging demand for an integrated vision/force approach. This emerging demand is not surprising, since the development of combined vision/force applications is only a natural step in the evolution of sensor based robotics.

Evidently, the integrated vision/force approach combines the advantages of both sensors, while overcoming their individual drawbacks. Moreover, in contrast to what one might expect, the effort needed to accomplish a combined vision/force task is less than the sum of the efforts needed for both visual servoing and force control applied separately. After all, avoiding collision or depth estimation in a pure visual servoing task or detecting a change in the contact situation, e.g. at a corner, in a force controlled task are annoying operations which are hard to deal with. Using both sensors together remedies these shortcomings. In fact, this brings us back to the comparison with the human manipulator. We humans seamlessly switch or choose between touch and vision to accomplish a wide range of tasks, following one golden rule of thumb – true for both humans and sensor based robotics – : 'Assign specific tasks to that sensing ability which is best suited to perform the task'.

At this point, I'd like to express my gratitude to my supervisors and colleagues of the department of Industrial Sciences and Technology at the Katholieke Hogeschool Limburg, for the time and opportunity offered, and to my supervisors and colleagues of the department of Mechanical Engineering at the the Katholieke Universiteit Leuven, for their support and guidance. I'd further like to thank prof. Luc Vangool, prof. Hendrik Van Brussel, prof. Jan Swevers and prof. Herman Bruyninckx from the K.U.Leuven, and prof. Bruno Siciliano from the Università degli Studi di Napoli Federico II (Italy) for their efforts to my account.

Sint-Truiden, April 2003 *Johan Baeten*

This monograph is based on the PhD research work carried out by Johan Baeten under my supervision. It is the result of five years of fruitful collaboration (1996-2001) during which Johan was both a lecturer at the Katholieke Hogeschool Limburg and a part-time researcher at K.U.Leuven. In this work we tried to bring together force control and visual servoing in one common control framework and examine potential applications. We gratefully acknowledge financial support from the Belgian Interuniversity Poles of Attraction Programme, initiated by the Belgian State, Prime Minister's Office, Science Programming and from the K.U.Leuven Concerted Research Action GOA/99/04.

Johan's PhD thesis was selected as a finalist of the EURON Georges Giralt PhD Award - Second Edition. Of course we are very proud and honoured that this work was appreciated by the EURON PhD Award selection committee and we are very grateful for the offer to give it wider exposure by the publication of this book.

Research on robot force control at the Division of Production Engineering, Machine Design and Automation (PMA) of K.U.Leuven started in 1974 under the direction of Professor Hendrik Van Brussel. Jos Simons was his first PhD student. In 1980 he finished his PhD on the *Active Adaptable Compliance Wrist (AACW)*, which was proposed as a universal solution for the force feedback problem in robotic assembly. In his (3D) experiments Jos introduced adaptable passive compliance and combined it with active force feedback. The work even included learning behaviour! After obtaining his PhD, Jos spent one year at the Jet Propulsion Lab in Pasadena working on off-line robot programming. Back in Leuven in 1981, he interfaced a Cincinnati-T3 Milacron robot to a HP1000 minicomputer, wrote an off-line programming library, and started experiments with real-time force control and (Kalman filter based) visual servoing. This work was done in collaboration with Jayantha Katupitiya (PhD in 1985, now at the University of New South Wales in Sydney) for the visual servoing part, and myself for the force control part (PhD in 1986). Jos left the university in 1983 for a job in industry. Unfortunately, he passed away just a few months ago, in September 2002, at the age of 51. Twenty years later we can only conclude that Jos was a true robotics pioneer and visionary, and that by changing over to industry he missed a brilliant career as a robotics researcher. The publication of this book is the right occasion to pay tribute to him. The work presented in this book is based on his early ideas, approaches and experiments, which continue to inspire us every day. Therefore we dedicate this book to him.

Leuven, April 2003 *Joris De Schutter*

Additional information, movies of the experiments, a camera calibration toolbox, the graphical user interface for contour fitting and some programming code are available on `http://www.khlim.be/~jbaeten/star.html`

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