Lecture Notes in Control and Information Sciences 401

Editors: M. Thoma, F. Allgöwer, M. Morari

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Visual Servoing via Advanced Numerical Methods

Springer

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ISBN 978-1-84996-088-5 e-ISBN 978-1-84996-089-2

DOI 10.1007/978-1-84996-089-2

Lecture Notes in Control and Information Sciences ISSN 0170-8643

Library of Congress Control Number: Applied for

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

Printed on acid-free paper

5 4 3 2 1 0

springer.com

To my family Shing Chee, Isabella and Sofia (GC).

To my family Ritsuko, Riho, Daisuke, Kanta, Teppei and Shogo (KH).

This book is dedicated in memory of Dr. Ryosuke Mori (1972–2008).

Preface

Robots able to imitate human beings have been at the core of stories of science fiction as well as dreams of inventors for a long time. Among the various skills that Mother Nature has provided us with and that often go forgotten, the ability of sight is certainly one of the most important. Perhaps inspired by tales of Isaac Asimov, comics and cartoons, and surely helped by the progress of electronics in recent decades, researchers have progressively made the dream of creating robots able to move and operate by exploiting artificial vision a concrete reality.

Technically speaking, we would say that these robots position themselves and their end-effectors by using the view provided by some artificial eyes as feedback information. Indeed, the artificial eyes are visual sensors such as cameras that have the function to acquire an image of the environment. Such an image describes if and how the robot is moving toward the goal and hence constitutes feedback information. This procedure is known in robotics with the term *visual servoing*, and it is nothing else than an imitation of the intrinsic mechanism that allows human beings to realize daily tasks such as reaching the door of the house or grasping a cup of coffee.

Hence, there is no need to say that visual servoing is one of the hottest areas of robotics. Indeed, visual servoing can be, and is, exploited in numerous and various applications, such as industry, surveillance, transportation, exploration, surgery, and the replacement of human beings in dangerous environments. This book aims to provide a collection of the latest advances in visual servoing, which have been achieved through the development of dedicated numerical methods that the recent progress in video devices, computer hardware, and optimization techniques, have made possible.

Organization of the Book

The book is organized in three main parts, reflecting three main classes of issues in visual servoing.

The first part, *Vision*, comprises contributions whose main focus is on vision issues that characterize visual servoing tasks. Specifically, Mariottini *et al.* introduce visual servoing via catadioptric stereo with planar mirrors. Swensen *et al.* analyze convergence properties of featureless visual servoing. Namiki *et al.* propose a high-speed vision system for grasping and manipulation. Hager considers human-machine cooperation via vision-based motion constraints. Collewet and Marchand propose luminance as a new feature for visual servoing. Bachta *et al.* address vision issues in beating heart surgery.

The second part, *Estimation and Path-planning*, collects contributions whose main focus is on estimation issues and path-planning strategies. Specifically, Mezouar addresses trajectory planning via variational calculous. Malis *et al.* consider the estimation of homography dynamics. Chesi *et al.* investigate the effect of image measurement errors on the positioning error. Danes *et al.* analyze visual servoing through rational systems and linear matrix inequalities (LMIs). Kazemi *et al.* present a review of path-planning methods. Dani and Dixon consider structure and motion estimation with single camera. Tahri *et al.* address visual servoing and pose estimation with cameras obeying the unified model.

Lastly, the third part, *Control*, focuses on control issues of visual servoing tasks. Specifically, Ma and Hutchinson present gradient projection methods for taking into account constraints in image-based visual servoing (IBVS). Tarbouriech and Soueres address multi-constraint satisfaction in IBVS via LMIs. Hadj-Abdelkader *et al.* present a control scheme with central cameras. Lamiraux and Lefebvre describe deformation-based trajectory control for nonholonomic robots. Belo *et al.* consider eye-in-hand unicycle-like robots via position-based visual servoing and IBVS. Iwatani *et al.* address occlusion avoidance in unmanned helicopter control. Allibert *et al.* propose the use of nonlinear predictive control in visual servoing.

Acknowledgements

We thank the authors of the chapters for their precious contributions that have made possible to realize this great collection of advanced numerical methods for visual servoing. And we also thank the Springer Editors for their patience and suggestions that have helped us in the difficult task of editing a book.

This book was typeset by the authors using LaTeX.

Hong Kong
Sendai
September 2009

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Part I: Vision

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Abbreviations

AOI	Area of interest
ARIMAX	Autoregressive and integrated moving average with exogenous input
BQLF	Biquadratic Lyapunov function
CABG	Coronary artery bypass grafting
CCD	Charge-coupled device
CISST	Center for computer integrated surgical systems
CPV	Column-parallel high speed vision system
DA	Digital analog
DAR	Differential algebraic representation
DDR	Differential drive robot
DOF	Degrees of freedom
ECG	Electrocardiogram
EKF	Extended Kalman filter
ERSP	Evolution robotics software platform
ESM	Efficient second order minimization
FLC	Fourier linear combiner
FOV	Field of view
GN	Gauss–Newton
GPC	Generalized predictive controller
GPS	Global positioning system
IBO	Identifier-based observer
IBVS	Image-based visual servoing
IMC	Internal model control
IMU	Inertial measurement unit
JHU	Johns Hopkins University
MfS	Motion from structure
MIS	Minimally invasive surgery
MLM	Modified Levenberg–Marquardt
MRI	Magnetic resonance imaging
KBVS	Kernel-based visual servoing

KLT	Kanade–Lucas–Tomasi
LED	Light emitting diode
LMI	Linear matrix inequality
OECD	Organization for economic cooperation and development
OFCE	Optical flow constraint equation
PBVS	Position-based visual servoing
PC	Personal computer
PCI	Percutaneous coronary intervention
PCM	Perceptual control manifold
PCS	Planar catadioptric stereo
PD	Proportional derivative
PID	Proportional integral derivative
PW-BQLF	Piecewise-biquadratic Lyapunov function
RLS	Recursive least-squares
SaM	Structure and motion
SfM	Structure from motion
SHR	Steady hand robot
SDP	Semidefinite programming
SIFT	Scale-invariant feature transform
SLAM	Simultaneous localization and mapping
SMR	Square matricial representation
SOS	Sum of squares of polynomials
SQP	Sequential quadratic program
TECAB	Totally endoscopic coronary artery bypass
UUB	Uniformly ultimately bounded
VPC	Visual predictive control
VSLAM	Visual simultaneous localization and mapping
VVS	Virtual visual servoing