LNCIS

LECTURE NOTES IN CONTROL AND INFORMATION SCIENCES

362

Tzyh-Jong Tarn
Shan-Ben Chen
Changjiu Zhou (Eds.)

Robotic Welding, Intelligence and Automation

Springer

Tzyh-Jong Tarn, Shan-Ben Chen,
Changjiu Zhou (Eds.)

Robotic Welding, Intelligence and Automation

Springer

Editors

Tzyh-Jong Tarn

Cupples 2, Room 103
Campus Box 1040
Washington University
St. Louis, MS 63130
USA
Email: Tarn@wuauto.wustl.edu

Shan-Ben Chen

Institute of Welding Engineering
Shanghai Jiao Tong University
Shanghai, 200030
P.R. China
Email: sbchen@sjtu.edu.cn

Changjiu Zhou

Advanced Robotics and Intelligent
Control Centre (ARICC)
School of Electrical and
Electronic Engineering
Singapore Polytechnic
500 Dover Road
Singapore 139651
Singapore
Email: ZhouCJ@sp.edu.sg

Library of Congress Control Number: 2007927163

ISSN print edition: 0170-8643
ISSN electronic edition: 1610-7411
ISBN-10 3-540-73373-6 Springer Berlin Heidelberg New York
ISBN-13 978-3-540-73373-7 Springer Berlin Heidelberg New York

Springer is a part of Springer Science+Business Media
springer.com

Typesetting: by the authors and SPS using a Springer LaTeX macro package

Printed on acid-free paper SPIN: 11898481 89/SPS 5 4 3 2 1 0

Lecture Notes in Control and Information Sciences 362

Editors: M. Thoma, M. Morari

Preface

Robotic welding systems have been used in different types of manufacturing. They can provide several benefits in welding applications. The most prominent advantages of robotic welding are precision and productivity. Another benefit is that labor costs can be reduced. Robotic welding also reduces risk by moving the human welder/operator away from hazardous fumes and molten metal close to the welding arc. The robotic welding system usually involves measuring and identifying the component to be welded, welding it in position, controlling the welding parameters and documenting the produced welds. However, traditional robotic welding systems rely heavily upon human intervention. It does not seem that the traditional robotic welding techniques by themselves can cope well with uncertainties in the welding surroundings and conditions, e.g. variation of weld pool dynamics, fluxion, solid, weld torch, and etc. On the other hand, the advent of intelligent techniques provides us with a powerful tool for solving demanding real-world problems with uncertain and unpredictable environments. Therefore, it is interesting to gather current trends and to provide a high quality forum for engineers and researchers working in the filed of intelligent techniques for robotic welding systems. This volume brings together a broad range of invited and contributed papers that describe recent progress in this field.

This volume is mainly based on the papers selected from the 2006 International Conference on Robotic Welding, Intelligence and Automation (RWIA'2006), December 8-11, 2006, Shanghai, China, which was supported by the National Natural Science Foundation of China (NSFC) and the special fund for international conference of Shanghai Jiao Tong University. We have also invited some known authors as well as announced a formal Call for Papers to several research groups related to welding robotics and intelligent systems to contribute the latest progress and recent trends and research results in this field. The primary aim of this volume is to provide researchers and engineers from both academic and industry with up-to-date coverage of new results in the field of robotic welding, intelligent systems and automation.

The volume is divided into five logical parts containing sixty-four papers. In Part 1 (11 papers), the authors introduce the recent development of intelligent robotics. In Part 2 (18 papers), the authors deal with some intelligent techniques for robotic welding. In Part 3 (11 papers), the authors describe their work on vision sensing and intelligent control of arc welding processing. Various applications such as vision sensing and control of welding process are discussed. In Part 4 (8 papers), the authors present different applications of welding automation. Finally, in Part 5 (16 papers), the authors introduce some emerging intelligent control techniques and their applications, which may contribute significantly to the further development of intelligent robotic welding systems.

We would like to thank Professors R. C. Luo, T. Fukuda, X.P. Yun, J.L. Pan, C.B. Feng, S.Z. Yang, B.S. Xu, S.Y. Lin, T.R. Wang, S.W. Xie, T.H. Song, L. Wu, Y.X. Wu for their kind advice and support to the organization of the RWIA'2006 and the publication of this book; to Drs Hongbo Ma, Fanhuai Shi, Xixia Huang, Jing Wu, Fenglin Lv for their precious time to devote all RWIA'2006 correspondences and to reformat and edit the most final submissions into the required format of the book; to Dr Lingyun Hu, Advanced Robotics and Intelligent Control Centre (ARICC) of Singapore Polytechnic, for her editorial assistance, last but not least to Dr. Thomas Ditzinger for his advice and help during the production phases of this book.

December 2006

Tzyh-Jong Tarn, Washington University at St. Louis, USA
Shan-Ben Chen, Shanghai Jiao Tong University, China
Changjiu Zhou, Singapore Polytechnic, Singapore

Lecture Notes in Control and Information Sciences

Edited by M. Thoma, M. Morari

Further volumes of this series can be found on our homepage:
springer.com

Vol. 362: Tarn T.-J.; Chen S.-B.; Zhou C. (Eds.)
Robotic Welding, Intelligence and Automation
562 p. 2007 [978-3-540-73373-7]

Vol. 361: Méndez-Acosta H.O.; Femat R.; González-Álvarez V. (Eds.):
Selected Topics in Dynamics and Control of Chemical and Biological Processes
320 p. 2007 [978-3-540-73187-0]

Vol. 360: Kozlowski K. (Ed.)
Robot Motion and Control 2007
452 p. 2007 [978-1-84628-973-6]

Vol. 359: Christophersen F.J.
Optimal Control of Constrained Piecewise Affine Systems
190 p. 2007 [978-3-540-72700-2]

Vol. 358: Findeisen R.; Allgöwer F.; Biegler L.T. (Eds.): Assessment and Future Directions of Nonlinear Model Predictive Control
642 p. 2007 [978-3-540-72698-2]

Vol. 357: Queinnec I.; Tarbouriech S.; Garcia G.; Niculescu S.-I. (Eds.):
Biology and Control Theory: Current Challenges
589 p. 2007 [978-3-540-71987-8]

Vol. 356: Karatkevich A.:
Dynamic Analysis of Petri Net-Based Discrete Systems
166 p. 2007 [978-3-540-71464-4]

Vol. 355: Zhang H.; Xie L.:
Control and Estimation of Systems with Input/Output Delays
213 p. 2007 [978-3-540-71118-6]

Vol. 354: Witczak M.:
Modelling and Estimation Strategies for Fault Diagnosis of Non-Linear Systems
215 p. 2007 [978-3-540-71114-8]

Vol. 353: Bonivento C.; Isidori A.; Marconi L.; Rossi C. (Eds.)
Advances in Control Theory and Applications
305 p. 2007 [978-3-540-70700-4]

Vol. 352: Chiasson, J.; Loiseau, J.J. (Eds.)
Applications of Time Delay Systems
358 p. 2007 [978-3-540-49555-0]

Vol. 351: Lin, C.; Wang, Q.-G.; Lee, T.H., He, Y.
LMI Approach to Analysis and Control of Takagi-Sugeno Fuzzy Systems with Time Delay
204 p. 2007 [978-3-540-49552-9]

Vol. 350: Bandyopadhyay, B.; Manjunath, T.C.; Umapathy, M.
Modeling, Control and Implementation of Smart Structures 250 p. 2007 [978-3-540-48393-9]

Vol. 349: Rogers, E.T.A.; Galkowski, K.; Owens, D.H.
Control Systems Theory and Applications for Linear Repetitive Processes 482 p. 2007 [978-3-540-42663-9]

Vol. 347: Assawinchaichote, W.; Nguang, K.S.; Shi P.
Fuzzy Control and Filter Design for Uncertain Fuzzy Systems
188 p. 2006 [978-3-540-37011-6]

Vol. 346: Tarbouriech, S.; Garcia, G.; Glattfelder, A.H. (Eds.)
Advanced Strategies in Control Systems with Input and Output Constraints
480 p. 2006 [978-3-540-37009-3]

Vol. 345: Huang, D.-S.; Li, K.; Irwin, G.W. (Eds.)
Intelligent Computing in Signal Processing and Pattern Recognition
1179 p. 2006 [978-3-540-37257-8]

Vol. 344: Huang, D.-S.; Li, K.; Irwin, G.W. (Eds.)
Intelligent Control and Automation
1121 p. 2006 [978-3-540-37255-4]

Vol. 341: Commault, C.; Marchand, N. (Eds.)
Positive Systems
448 p. 2006 [978-3-540-34771-2]

Vol. 340: Diehl, M.; Mombaur, K. (Eds.)
Fast Motions in Biomechanics and Robotics
500 p. 2006 [978-3-540-36118-3]

Vol. 339: Alamir, M.
Stabilization of Nonlinear Systems Using Receding-horizon Control Schemes
325 p. 2006 [978-1-84628-470-0]

Vol. 338: Tokarzewski, J.
Finite Zeros in Discrete Time Control Systems
325 p. 2006 [978-3-540-33464-4]

Vol. 337: Blom, H.; Lygeros, J. (Eds.)
Stochastic Hybrid Systems
395 p. 2006 [978-3-540-33466-8]

Vol. 336: Pettersen, K.Y.; Gravdahl, J.T.; Nijmeijer, H. (Eds.)
Group Coordination and Cooperative Control
310 p. 2006 [978-3-540-33468-2]

Vol. 335: Kozłowski, K. (Ed.)
Robot Motion and Control
424 p. 2006 [978-1-84628-404-5]

Vol. 334: Edwards, C.; Fossas Colet, E.; Fridman, L. (Eds.)
Advances in Variable Structure and Sliding Mode Control
504 p. 2006 [978-3-540-32800-1]

Vol. 333: Banavar, R.N.; Sankaranarayanan, V.
Switched Finite Time Control of a Class of Underactuated Systems
99 p. 2006 [978-3-540-32799-8]

Vol. 332: Xu, S.; Lam, J.
Robust Control and Filtering of Singular Systems
234 p. 2006 [978-3-540-32797-4]

Vol. 331: Antsaklis, P.J.; Tabuada, P. (Eds.)
Networked Embedded Sensing and Control
367 p. 2006 [978-3-540-32794-3]

Vol. 330: Koumoutsakos, P.; Mezic, I. (Eds.)
Control of Fluid Flow
200 p. 2006 [978-3-540-25140-8]

Vol. 329: Francis, B.A.; Smith, M.C.; Willems, J.C. (Eds.)
Control of Uncertain Systems: Modelling, Approximation, and Design
429 p. 2006 [978-3-540-31754-8]

Vol. 328: Loría, A.; Lamnabhi-Lagarrigue, F.; Panteley, E. (Eds.)
Advanced Topics in Control Systems Theory
305 p. 2006 [978-1-84628-313-0]

Vol. 327: Fournier, J.-D.; Grimm, J.; Leblond, J.; Partington, J.R. (Eds.)
Harmonic Analysis and Rational Approximation
301 p. 2006 [978-3-540-30922-2]

Vol. 326: Wang, H.-S.; Yung, C.-F.; Chang, F.-R.
H_∞ Control for Nonlinear Descriptor Systems
164 p. 2006 [978-1-84628-289-8]

Vol. 325: Amato, F.
Robust Control of Linear Systems Subject to Uncertain
Time-Varying Parameters
180 p. 2006 [978-3-540-23950-5]

Vol. 324: Christofides, P.; El-Farra, N.
Control of Nonlinear and Hybrid Process Systems
446 p. 2005 [978-3-540-28456-7]

Vol. 323: Bandyopadhyay, B.; Janardhanan, S.
Discrete-time Sliding Mode Control
147 p. 2005 [978-3-540-28140-5]

Vol. 322: Meurer, T.; Graichen, K.; Gilles, E.D. (Eds.)
Control and Observer Design for Nonlinear Finite and Infinite Dimensional Systems
422 p. 2005 [978-3-540-27938-9]

Vol. 321: Dayawansa, W.P.; Lindquist, A.; Zhou, Y. (Eds.)
New Directions and Applications in Control Theory
400 p. 2005 [978-3-540-23953-6]

Vol. 320: Steffen, T.
Control Reconfiguration of Dynamical Systems
290 p. 2005 [978-3-540-25730-1]

Vol. 319: Hofbaur, M.W.
Hybrid Estimation of Complex Systems
148 p. 2005 [978-3-540-25727-1]

Vol. 318: Gershon, E.; Shaked, U.; Yaesh, I.
H_∞ Control and Estimation of State-multiplicative Linear Systems
256 p. 2005 [978-1-85233-997-5]

Vol. 317: Ma, C.; Wonham, M.
Nonblocking Supervisory Control of State Tree Structures
208 p. 2005 [978-3-540-25069-2]

Vol. 316: Patel, R.V.; Shadpey, F.
Control of Redundant Robot Manipulators
224 p. 2005 [978-3-540-25071-5]

Vol. 315: Herbordt, W.
Sound Capture for Human/Machine Interfaces: Practical Aspects of Microphone Array Signal Processing
286 p. 2005 [978-3-540-23954-3]

Vol. 314: Gil', M.I.
Explicit Stability Conditions for Continuous Systems
193 p. 2005 [978-3-540-23984-0]

Vol. 313: Li, Z.; Soh, Y.; Wen, C.
Switched and Impulsive Systems
277 p. 2005 [978-3-540-23952-9]

Vol. 312: Henrion, D.; Garulli, A. (Eds.)
Positive Polynomials in Control
313 p. 2005 [978-3-540-23948-2]

Vol. 311: Lamnabhi-Lagarrigue, F.; Loría, A.; Panteley, E. (Eds.)
Advanced Topics in Control Systems Theory
294 p. 2005 [978-1-85233-923-4]

Vol. 310: Janczak, A.
Identification of Nonlinear Systems Using Neural Networks and Polynomial Models
197 p. 2005 [978-3-540-23185-1]

Vol. 309: Kumar, V.; Leonard, N.; Morse, A.S. (Eds.)
Cooperative Control
301 p. 2005 [978-3-540-22861-5]

Vol. 308: Tarbouriech, S.; Abdallah, C.T.; Chiasson, J. (Eds.)
Advances in Communication Control Networks
358 p. 2005 [978-3-540-22819-6]

¥1291.00元

Contents

Part II: Intelligent Techniques for Robotic Welding

Behavior-Based Intelligent Robotic Technologies in Industrial Applications

Z.X. Gan[1], H. Zhang[2], and J.J. Wang[2]

[1] Robotics Department, ABB Corporate Research Center, Shanghai, P.R. China, 200131
[2] ABB Corporate Research, Windsor, CT, USA, 06095
Zhongxue.gan@cn.abb.com

Abstract. This paper gives a brief review on intelligent robotic technologies in industrial applications. The goal is not to conduct a thorough analysis of the state-of-art technologies, but rather to point out the directions for future technology development. Based on the market success of force control and machine vision in industry automation, this paper contends the arrival of the golden period of intelligent robotic technologies. The potential growth markets at present and in the near future are primarily assembly, and machining, where vision and force sensing continue to be the enabling technologies. As robot manufacturers start to embrace this technology wave, there are many technical challenges to be solved. The major problem for industrial R&D is how to safely and cost-effectively integrate sensor-driven functionalities with existing pure planning based position control system. For academic research, robust, efficient and effective sensor fusion and data mining methods should be the focus.

1 Introduction

It has been forty years since the first industrial robot called UNIMATE was online in a General Motors automobile factory in 1961. Automotive is still the primary industry for industrial robots, although its share has constantly decreased over the years as robots expand to general industries like plastics, food, consumer, and pharmaceutics. Worldwide, spot welding, arc welding, and material handling are still the dominant applications, where robots are mainly used to move materials, parts, tools, or specialized devices through various programmed motions. Contrary to the highly intelligent creatures described in science fiction, current industrial robots are deaf and dumb devices, working in a perfectly created and controlled environment. Expensive and often inflexible peripheral devices, such as conveyors, pallets, grippers and positioners, are the building elements of this well structured environment to provide accurate fixturing, tooling and positioning for the robot.

The unambiguousness of a structured environment provides unparallel repeatability, shorter cycle time and deterministic behavior of a robotized cell or line, at expense of cost and flexibility. Only large volume production can afford this kind of setup. This explains why the majority of current robot users are big revenue companies such as automotive manufacturers.

It is amazing that this approach dominates robotics industry since the birth of first industrial robot, while at the same period computer and sensor technologies have

T.-J. Tarn et al. (Eds.): Robot. Weld., Intellige. & Automation, LNCIS 362, pp. 1–12, 2007.
springerlink.com

advanced dramatically. It is until the beginning of 21st century automotive industries officially accepted sensor-assisted intelligent robots running on their production floors. The reception of Henry Ford Technology award by BrainTech's TrueView technology marks a historic turning point, the beginning of a golden period for intelligent robotic technologies.

2 Success of Machine Vision in Robotics Automation Marks the Start of the Golden Period for Intelligent Robotic Technologies

Unlike a LVDT sensor that can be immediately plugged and readily used, machine vision is one of the most complicated sensor technologies. Firstly it demands very stringent setup to ensure proper lighting, correct field of view and clean lens protection. Classic stories of early machine vision spoke of applications that were successfully installed at plants but failed when the season changed or sunlight came in a nearby window. Secondly, to get useful information from images, high computation power is needed. This explains why machine vision systems in 1980s and 1990s were often quite bulky and expensive. Thirdly, robust image processing algorithms are very difficult to design to suit different kinds of applications. A machine vision system often requires careful customization before the deployment.

With such complexity, it is not surprising that it took twenty years for vision technology to enter automotive production floor, although most of the theoretical advances that form the basis of modern industrial machine vision existed since 1980s. The recent history of machine vision is essentially the history of the adaptation of evolving computer technology to the commercialization of image processing for industrial automation. Vision system has become much faster, cheaper and smaller, but at the same time much simpler to use.

The success of machine vision in robotics automation is significant. It not only demonstrates that intelligent technologies are mature and ready to be used in industrial environment, but more importantly it refreshes the image of sensor based intelligent technologies, once perceived unreliable and costly by automation industry. The doors leading to huge amount of opportunities are now opened. As a result, one could declare that the success of machine vision in robotics automation marks the golden period of intelligent technologies.

Now days, once viewed largely as a way to save on labor costs, robots have taken on more significant roles in manufacturing with the growing intelligent capabilities. They have become part of global competitiveness plans, when manufacturing industry faces unprecedented cost pressure for outsourcing. North American manufacturing industry has realized, for tomorrow's manufacturing winners, the competitive determinant will be how robots fit into a total manufacturing/automation strategy -- not just labor cost. In this competition, sensor based intelligent technologies will play a vital role.

3 Current Successful Intelligent Robotic Technologies

Sensor based intelligent technologies, especially machine vision, have already achieved market successes in several applications, among which are seam tracking in welding application and vision-aided part locating in packaging applications.

3.1 Seam Tracking in Welding System

One of the earliest implementations of machine vision in robotics was in welding (Fig.1). Today welding vision has become important part of robotic welding system.

Fig. 1. Laser vision Seam Tracker™ from Meta vision systems (www.meta-mvs.com)

Seam Tracker™ is a laser seam tracking system designed for high performance applications such as spiral pipe manufacture and tailor welded blanks. Using data acquired from the sensor the control system will display joint geometry, the gap and mismatch as well as calculate the optimum lateral and vertical position of the weld torch.

Welding vision systems are generally based on structured light or range data collection. In the case of structured light-based systems, laser diodes are used to project a pattern of light at a preset angle in the shape of a single line, multiple lines or a cone of light yielding a projected circle. Triangulation mathematics determines the Z-axis data. In the case of the range data arrangement, a laser light sweeps across the joint of the part(s) being welded and the time it takes the laser to reflect to the 3-D camera head determines the location of the joint. In both cases, the systems eliminate all wavelengths of light associated with the welding process by using filters that only pass the wavelength of light associated with the lasers used.

The use of welding vision in robot welders helps compensate the positional inaccuracy in the robot manipulator, part fixture and tooling and the workpiece itself. Programming the robot to follow complex weld joint paths is also simplified as the vision system can adjust the path automatically. In addition to that, some vision systems can also measure the width and depth of welds for real time process monitoring and control.

Welding vision systems are a proven technology in spite of the harsh environment. The payback from using welding vision is better weld quality, higher productivity, lower production costs and less environmental impact.

3.2 Vision Guided Part Locating in Packaging Applications

Not other robotized application is as much dependent on machine vision as packaging. The products to be packed, cookies, fruits, pills or mails, are simply placed randomly on the conveyor. A robot, synchronized with continuously moving conveyor, locates the position and the orientation of each part through its vision