

Editor-in-Chief

*A. Joe Turner, Seneca, SC, USA*

Editorial Board

Foundations of Computer Science

*Jacques Sakarovitch, Télécom ParisTech, France*

Software: Theory and Practice

*Michael Goedicke, University of Duisburg-Essen, Germany*

Education

*Arthur Tatnall, Victoria University, Melbourne, Australia*

Information Technology Applications

*Erich J. Neuhold, University of Vienna, Austria*

Communication Systems

*Aiko Pras, University of Twente, Enschede, The Netherlands*

System Modeling and Optimization

*Fredi Tröltzsch, TU Berlin, Germany*

Information Systems

*Jan Pries-Heje, Roskilde University, Denmark*

ICT and Society

*Diane Whitehouse, The Castlegate Consultancy, Malton, UK*

Computer Systems Technology

*Ricardo Reis, Federal University of Rio Grande do Sul, Porto Alegre, Brazil*

Security and Privacy Protection in Information Processing Systems

*Yuko Murayama, Iwate Prefectural University, Japan*

Artificial Intelligence

*Tharam Dillon, Curtin University, Bentley, Australia*

Human-Computer Interaction

*Jan Gulliksen, KTH Royal Institute of Technology, Stockholm, Sweden*

Entertainment Computing

*Matthias Rauterberg, Eindhoven University of Technology, The Netherlands*

## **IFIP – The International Federation for Information Processing**

IFIP was founded in 1960 under the auspices of UNESCO, following the First World Computer Congress held in Paris the previous year. An umbrella organization for societies working in information processing, IFIP's aim is two-fold: to support information processing within its member countries and to encourage technology transfer to developing nations. As its mission statement clearly states,

*IFIP's mission is to be the leading, truly international, apolitical organization which encourages and assists in the development, exploitation and application of information technology for the benefit of all people.*

IFIP is a non-profitmaking organization, run almost solely by 2500 volunteers. It operates through a number of technical committees, which organize events and publications. IFIP's events range from an international congress to local seminars, but the most important are:

- The IFIP World Computer Congress, held every second year;
- Open conferences;
- Working conferences.

The flagship event is the IFIP World Computer Congress, at which both invited and contributed papers are presented. Contributed papers are rigorously refereed and the rejection rate is high.

As with the Congress, participation in the open conferences is open to all and papers may be invited or submitted. Again, submitted papers are stringently refereed.

The working conferences are structured differently. They are usually run by a working group and attendance is small and by invitation only. Their purpose is to create an atmosphere conducive to innovation and development. Refereeing is also rigorous and papers are subjected to extensive group discussion.

Publications arising from IFIP events vary. The papers presented at the IFIP World Computer Congress and at open conferences are published as conference proceedings, while the results of the working conferences are often published as collections of selected and edited papers.

Any national society whose primary activity is about information processing may apply to become a full member of IFIP, although full membership is restricted to one society per country. Full members are entitled to vote at the annual General Assembly, National societies preferring a less committed involvement may apply for associate or corresponding membership. Associate members enjoy the same benefits as full members, but without voting rights. Corresponding members are not represented in IFIP bodies. Affiliated membership is open to non-national societies, and individual and honorary membership schemes are also offered.

Svetan Ratchev (Ed.)

# Precision Assembly Technologies and Systems

7th IFIP WG 5.5

International Precision Assembly Seminar, IPAS 2014

Chamonix, France, February 16-18, 2014

Revised Selected Papers



Springer

## Volume Editor

Svetan Ratchev  
The University of Nottingham  
Institute for Advanced Manufacturing  
University Park, Nottingham, NG7 2RD, UK  
E-mail: svetan.ratchev@nottingham.ac.uk

ISSN 1868-4238

ISBN 978-3-662-45585-2

DOI 10.1007/978-3-662-45586-9

e-ISSN 1868-422X

e-ISBN 978-3-662-45586-9

Springer Heidelberg New York Dordrecht London

Library of Congress Control Number: 2014953971

© IFIP International Federation for Information Processing 2014

This work is subject to copyright. All rights are reserved by the Publisher, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilms or in any other physical way, and transmission or information storage and retrieval, electronic adaptation, computer software, or by similar or dissimilar methodology now known or hereafter developed. Exempted from this legal reservation are brief excerpts in connection with reviews or scholarly analysis or material supplied specifically for the purpose of being entered and executed on a computer system, for exclusive use by the purchaser of the work. Duplication of this publication or parts thereof is permitted only under the provisions of the Copyright Law of the Publisher's location, in its current version, and permission for use must always be obtained from Springer. Permissions for use may be obtained through RightsLink at the Copyright Clearance Center. Violations are liable to prosecution under the respective Copyright Law.

The use of general descriptive names, registered names, trademarks, service marks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

While the advice and information in this book are believed to be true and accurate at the date of publication, neither the authors nor the editors nor the publisher can accept any legal responsibility for any errors or omissions that may be made. The publisher makes no warranty, express or implied, with respect to the material contained herein.

*Typesetting:* Camera-ready by author, data conversion by Scientific Publishing Services, Chennai, India

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

# Foreword

The book includes a selected set of papers presented at the 7<sup>th</sup> International Precision Assembly Seminar (IPAS 2014) held in Chamonix, France, in February 2014. The International Precision Assembly Seminar, which was established in 2003 by the European Thematic Network Assembly-Net, has developed the premier international event for presenting and discussing the latest research, new innovative technologies, and industrial applications in the area of precision assembly.

We consider precision assembly as a process that covers a wide range of products where handling, positioning, manipulation, and joining technologies are constrained by specific quality, accuracy, and repeatability requirements that cannot be met by conventional assembly methods. At the micro-scale, a distinctive feature of precision assembly is that surface forces are often dominant over gravity forces, which determines a number of specific technical challenges including high-accuracy positioning and manipulation techniques, micro-gripping methods that take into account the surface forces, high-precision micro-feeding techniques, and micro-joining processes. At the other end of the scale, there are specific challenges in industries such as aerospace poised by the need to assemble large structures with extremely small tolerances that usually require additional metrology assistance and further equipment and process enhancement.

Precision assembly of complex high-value products is a key manufacturing process in sectors such as the automotive and aerospace sectors, and in defence, pharmaceutical, and medical industries. Some of the common trends underlining the development of precision assembly systems in these sectors include: increased demand for rapid ramp-up and downscale of production systems; increased demand for assembly systems that can react to disruptive events and fluctuations during the production process; and a drive toward after-sales service contracts for maintenance and equipment upgrade.

The book is structured into six chapters. Chapter 1 includes papers dedicated to micro-assembly processes and systems ranging from desktop factory automation and packaging of MEMS to self-assembly processes and platforms. Chapter 2 is focused on handling and manipulation and includes contributions on flexible gripper systems, fixturing, and high-precision actuators. Chapter 3 includes a range of contributions on tolerance management and error-compensation techniques applied at different scales of precision assembly. Chapter 4 describes some of the latest developments in metrology and quality control, while Chapter 5 introduces contributions on intelligent assembly control. Finally, Chapter 6 concludes with contributions on process selection, modelling, and planning.

The seminar is sponsored by the International Federation of Information Processing (IFIP) WG5.5, the International Academy of Production Research (CIRP), and the European Factory Automation Committee (EFAC). The

seminar is supported by a number of ongoing research initiatives and projects including the European sub-technology platform in Micro and Nano Manufacturing MINAM 2.0, as well as the EU Framework 7-funded collaborative projects PRIME and COPERNICO.

The organizers should like to express their gratitude to the members of the international Advisory Committee for their support and guidance and to the authors of the papers for their original contributions. Special thanks go to Ruth Strickland and Rachel O'Shea from the Precision Manufacturing Centre at the University of Nottingham for handling the administrative aspects of the seminar, putting the proceedings together, and managing the detailed liaison with the authors and the publishers.

October 2014

Svetan Ratchev

# Organization

## Seminar Chair

Svetan Ratchev  
Director of the Institute for Advanced  
Manufacturing, University of Nottingham,  
UK

## Keynote Speakers

Danick Bionda  
Irene Fassi  
General Secretary of Micronarc, Switzerland  
Head of Micro Enabled Devices and Systems  
Research Unit, ITIA-CNR, Institute of  
Industrial Technologies and Automation,  
National Research Council, Milan, Italy

James Kell  
On-Platform Repair Technology Specialist,  
Rolls-Royce, UK

Benedetto Vigna  
Executive Vice President, General Manager  
of the Analog, MEMS and Sensors Group of  
STMicroelectronics, Switzerland

## Session Chairs

Markus Dickerhof  
The Karlsruhe Institute of Technology,  
Germany

Jacques Jacot  
EPFL, Switzerland

Pierre Lambert  
EPFL, Switzerland

Richard Leach  
National Physical Laboratory, Middlesex, UK

Timo Prusi  
Tampere University of Technology, Finland

Erik Puik  
Hogeschool, The Netherlands

Svetan Ratchev  
University of Nottingham, UK

Alexander Steinecker  
CSEM, Switzerland

## Local Organizing Committee

Evelyne Roudier-Poirot  
Manager of the Majestic Congress Centre and  
Convention Bureau of Chamonix, France

## Conference Administration

|                 |   |
|-----------------|---|
| Rachel O'Shea   | Project Administrator, University of Nottingham, UK |
| Ruth Strickland | Project Administrator, University of Nottingham, UK |

## International Advisory Committee

|                      |   |
|----------------------|---|
| T. Arai              | University of Tokyo, Japan                |
| H. Afsarmanesh       | University of Amsterdam, The Netherlands  |
| D Axinte             | University of Nottingham, UK              |
| M. Bjorkman          | Linkoping Institute of Technology, Sweden |
| H. Bley              | University of Saarland, Germany           |
| D. Branson           | University of Nottingham, UK              |
| L.M. Camarinho-Matos | Universidade Nova, Portugal               |
| J. Claverley         | National Physical Laboratory, UK          |
| A. Delchambre        | ULB, Belgium                              |
| M. Desmulliez        | Heriot-Watt University, UK                |
| S. Dimov             | University of Birmingham, UK              |
| G. Dini              | Univ di Pisa, Italy                       |
| S. Durante           | DIAD, Italy                               |
| K. Ehmann            | Northwestern University, USA              |
| Irene Fassi          | ITIA-CNR, Italy                           |
| R.W. Grubbstrom      | Linkoping Institute of Technology, Sweden |
| T. Hasegawa          | National College of Technology, Japan     |
| H. Krieger           | CSEM, Switzerland                         |
| P. Lambert           | ULB, Belgium                              |
| R. Leach             | National Physical Laboratory, UK          |
| N. Lohse             | University of Loughborough, UK            |
| P. Lutz              | LAB, France                               |
| H. Maekawa           | NIAI Science and Technology, Japan        |
| B. Nelson            | ETH, Switzerland                          |
| J. Ni                | University of Michigan, USA               |
| D. Pham              | University of Birmingham, UK              |
| M. Pillet            | Polytech Savoie, France                   |
| G. Putnik            | University of Minho, Portugal             |
| B. Raucent           | UCL, Belgium                              |
| K. Ridgway           | Sheffield University                      |
| K. Saitou            | University of Michigan, USA               |
| J. Segal             | University of Nottingham, UK              |
| W. Shen              | National Research Council of Canada       |



|                |                               |
|----------------|-------------------------------|
| M. Summers     | Airbus, UK                    |
| J. Heilala     | VTT, Finland                  |
| M. Tichem      | TU Delft, The Netherlands     |
| J. Jacot       | EPFL, Switzerland             |
| R. Tuokko      | TUT, Finland                  |
| P. Kinnell     | University of Nottingham, UK  |
| E. Westkamer   | Fraunhofer IPA, Germany       |
| S. Koelemeijer | Jaeger-Lecoultre, Switzerland |
| D. Williams    | Loughborough University, UK   |

## Sponsoring Organizations

The International Academy for Production Engineering



International Federation for Information Processing



# Table of Contents

|  |    |
|--|----|
| Robust Adhesive Precision Bonding in Automated Assembly Cells . . . . .  | 1  |
| <i>Tobias Müller, Sebastian Haag, Thomas Bastuck, Thomas Gisler,<br/>Hansruedi Moser, Petteri Uusimaa, Christoph Axt,<br/>and Christian Brecher</i>          |    |
| Assembly of Silicon Micro-parts with Steel Spindles Using<br>Low-Temperature Soldering . . . . .   | 8  |
| <i>Laurenz Notter and Jacques Jacot</i>  |    |
| Testing the Mechanical Characteristics and Contacting Behaviour<br>of Novel Manufactured and Assembled Sphere-Tipped Styli for<br>Micro-CMM Probes . . . . . | 15 |
| <i>Dong-Yea Sheu, James D. Claverley, and Richard K. Leach</i>   |    |
| Ultrasonic Press-Fitting: A New Assembly Technique . . . . .   | 22 |
| <i>Csaba Laurenczy, Damien Berlie, and Jacques Jacot</i>   |    |
| Precision Micro Assembly of Optical Components on MID and PCB . . . . .  | 30 |
| <i>Jonathan Seybold, Ulrich Kessler, Karl-Peter Fritz, and Heinz Kück</i>  |    |
| Integrated Tool-Chain Concept for Automated Micro-optics<br>Assembly . . . . .   | 37 |
| <i>Sebastian Haag, Tobias Müller, Christoph Pallasch,<br/>and Christian Brecher</i>  |    |
| Feeding of Small Components Using the Surface Tension of Fluids . . . . .  | 47 |
| <i>Matthias Burgard, Nabih Othman, Uwe Mai, Dirk Schlenker, and<br/>Alexander Verl</i>   |    |
| Precision Handling of Electronic Components for PCB Rework . . . . .   | 52 |
| <i>Gianmauro Fontana, Serena Ruggeri, Giovanni Legnani,<br/>and Irene Fassi</i>  |    |
| Shift Dynamics of Capillary Self-Alignment . . . . .   | 61 |
| <i>Gari Arutinov, Massimo Mastrangeli, Edsger C.P. Smits,<br/>Gert van Heck, Herman F.M. Schoo, Jaap J.M. den Toonder, and<br/>Andreas Dietzel</i>           |    |
| Image Stitching Based Measurements of Medical Screws . . . . .   | 69 |
| <i>Zoran Cenev, Timo Prusi, and Reijo Tuokko</i>   |    |

|  |     |
|--|-----|
| Concept of a Virtual Metrology Frame Based on Absolute Interferometry for Multi Robotic Assembly . . . . .   | 79  |
| <i>Robert Schmitt, Martin Peterek, and Stefan Quinders</i>   |     |
| Application of Deep Belief Networks for Precision Mechanism Quality Inspection . . . . .   | 87  |
| <i>Jianwen Sun, Alexander Steinecker, and Philipp Glocker</i>  |     |
| Visual Quality Inspection and Fine Anomalies: Methods and Application . . . . .  | 94  |
| <i>Simon-Frédéric Désage, Gilles Pitard, Maurice Pillet, Hugues Favrelière, Fabrice Frelin, Serge Samper, Gaëtan Le Goïc, Laurent Gwinner, and Pierre Jochum</i> |     |
| Control Methods in Microspheres Precision Assembly for Colloidal Lithography . . . . .   | 107 |
| <i>Olivier Delléa, Olga Shavdina, Pascal Fugier, Philippe Coronel, Emmanuel Ollier, and Simon-Frédéric Désage</i>  |     |
| A Multi-Agent System Architecture for Self-configuration . . . . .   | 118 |
| <i>Nikolas Antzoulatos, Elkin Castro, Daniele Scrimieri, and Svetan Ratchev</i>  |     |
| Process Module Construction Kit for Modular Micro Assembly Systems . . . . .   | 126 |
| <i>Raphael Adamietz, Tobias Iseringhausen, and Alexander Verl</i>  |     |
| Modular Workpiece Carrier System for Micro Production . . . . .  | 133 |
| <i>Tobias Iseringhausen, Raphael Adamietz, Dirk Schlenker, and Alexander Verl</i>  |     |
| A Generic Systems Engineering Method for Concurrent Development of Products and Manufacturing Equipment . . . . .  | 139 |
| <i>Erik Puik, Paul Gielen, Daniel Telgen, Leo van Moergestel, and Darek Ceglarek</i>   |     |
| The SMARTLAM 3D-I Concept: Design of Microsystems from Functional Elements Fabricated by Generative Manufacturing Technologies . . . . .                         | 147 |
| <i>Markus Dickerhof, Daniel Kimmig, Raphael Adamietz, Tobias Iseringhausen, Joel Segal, Nikola Vladov, Wilhelm Pflöging, and Maika Torge</i>                     |     |
| Optimal Design of Remote Center Compliance Devices of Rotational Symmetry . . . . .  | 161 |
| <i>Yang Liu and Michael Yu Wang</i>  |     |
| <b>Author Index</b> . . . . .  | 171 |