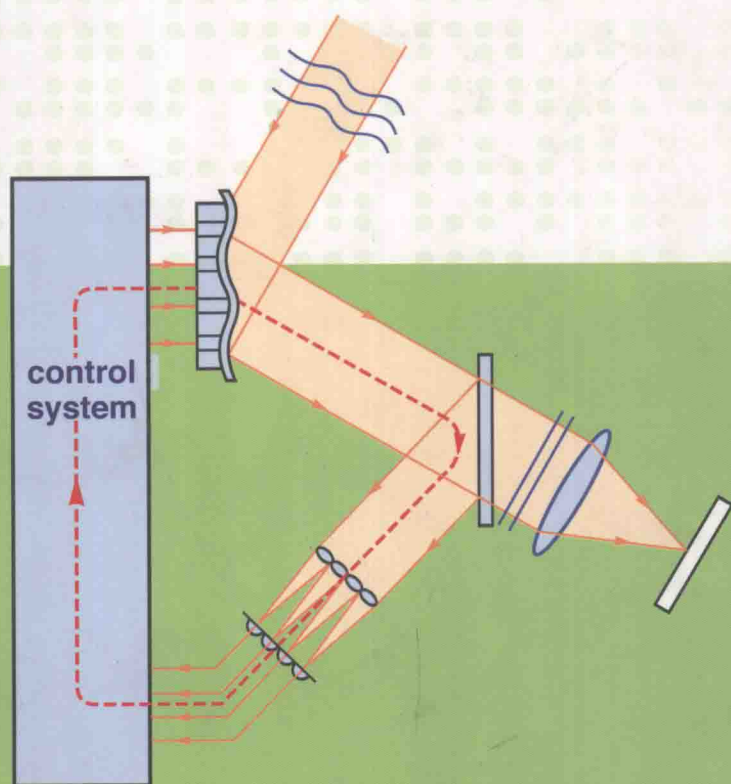


# Adaptive Optics for Industry and Medicine



**Christopher Dainty**  
*editor*

Imperial College Press

# Adaptive Optics for Industry and Medicine

Proceedings of the Sixth International Workshop

National University of Ireland, Ireland

12 – 15 June 2007

*editor*

**Christopher Dainty**

*National University of Ireland, Galway, Ireland &*

*Imperial College, London, UK*

*Published by*

Imperial College Press  
57 Shelton Street  
Covent Garden  
London WC2H 9HE

*Distributed by*

World Scientific Publishing Co. Pte. Ltd.

5 Toh Tuck Link, Singapore 596224

*USA office:* 27 Warren Street, Suite 401-402, Hackensack, NJ 07601

*UK office:* 57 Shelton Street, Covent Garden, London WC2H 9HE

**British Library Cataloguing-in-Publication Data**

A catalogue record for this book is available from the British Library.

**ADAPTIVE OPTICS FOR INDUSTRY AND MEDICINE**

**Proceedings of the Sixth International Workshop**

Copyright © 2008 by Imperial College Press

*All rights reserved. This book, or parts thereof, may not be reproduced in any form or by any means, electronic or mechanical, including photocopying, recording or any information storage and retrieval system now known or to be invented, without written permission from the Publisher.*

For photocopying of material in this volume, please pay a copying fee through the Copyright Clearance Center, Inc., 222 Rosewood Drive, Danvers, MA 01923, USA. In this case permission to photocopy is not required from the publisher.

ISBN-13 978-1-84816-110-8

ISBN-10 1-84816-110-7

# **Adaptive Optics for Industry and Medicine**

## Preface

The Sixth International Workshop on Adaptive Optics in Industry and Medicine took place in Galway, Ireland, from June 12-15, 2007. It was attended by approximately 130 delegates from 18 countries and also had a small exhibition with 12 companies participating. This series of Workshops started in 1997, with the first meeting being held in Shatura, Russia and subsequent ones being located in Durham (UK), Albuquerque (USA), Münster (Germany) and Beijing (China). This series is driven by grassroots activity in the field, and the relatively small size of the meetings has ensured an informal and lively occasion.

The subject of adaptive optics started with the publication by Horace Babcock, in 1953, of a paper describing how atmospheric turbulence may be compensated for in Earth-based telescopes. The idea was taken up by the US military in the 1970s and by astronomers in the late 1980s, and because of the demanding requirements for the then-available technology, adaptive optics was regarded as an expensive and sophisticated technique, to be undertaken only by big research and engineering teams. It was only in the late 1990s that people recognised that the basics of adaptive optics are not "rocket science", indeed they are very simple, and that through appropriate technological development, very high-quality but low cost adaptive optics systems could be constructed. Perhaps this is most vividly illustrated by the disclosure, at the Sixth Workshop, that adaptive optics is deployed in many DVD players at a cost of approximately 60 (euro-) cents per piece, and in quantities of more than one million per month. Another indication of the growing practicality of adaptive optics was the presence of many companies at this Workshop.

Organising any meeting, particularly one run at as low cost as possible, involves a significant volunteer effort. I would like to thank my colleagues on the Scientific Organising Committee for their help: Pablo Artal, John Gonglewski, Wenhan Jiang, Satoshi Kawata, Alexis Kudryashov, Gordon Love, Scot Olivier, Sergio Restaino, Robert Tyson, Ulrich Wittrock and Zhang Yudong. Local assistance was also provided by many people in the Applied Optics Group in Galway, with particular thanks to Emer McHugh and Una Murphy for administrative support. The Workshop was co-sponsored by The European Optical Society and by The Optical Society of America. Finally, the Workshop could not have been held without the financial support of many companies and organisations: Advanced Medical Optics, Andor Technologies, Bausch & Lomb Ireland, Boston Micromachine Corporation, CILAS, Fraunhofer Institut Photonische Mikrosysteme, Hamamatsu, Holoeye, Imagine Optics and Imagine Eyes, IrisAO, Night-N, OKO Flexible Optics, Optos, Phasics, Scimeasure, IDA Ireland, Enterprise Ireland, Fáilte Ireland and Science Foundation Ireland.

The Seventh International Workshop on Adaptive Optics in Industry and Medicine is due to be held in Russia in 2009, and I hope that many people reading this Proceedings will be able to attend that event.

Galway, October 2007

*Chris Dainty*



## Contents

Preface	v
 <b>Part 1 Wavefront Correctors and Control</b>	
Liquid crystal lenses for correction of presbyopia (Invited Paper) <i>Guoqiang Li and Nasser Peyghambarian</i>	3
Converging and diverging liquid crystal lenses (Oral Paper) <i>Andrew K. Kirby, Philip J.W. Hands, and Gordon D. Love</i>	9
Liquid lens technology for miniature imaging systems: status of the technology, performance of existing products and future trends (Invited Paper) <i>Bruno Berge</i>	14
Carbon fiber reinforced polymer deformable mirrors for high energy laser applications (Oral Paper) <i>S.R. Restaino, J.R. Andrews, R. Martin, T. Martinez, R. Romeo, C.C. Wilcox</i>	17
Tiny multilayer deformable mirrors (Oral Paper) <i>Tatiana Cherezova, Alexander Sobolev, Alexander Alexandrov, Alexey Kudryashov, and Vadim Samarkin</i>	23
Performance analysis of piezoelectric deformable mirrors (Oral Paper) <i>Oleg Soloviev, Mikhail Loktev and Gleb Vdovin</i>	29
Deformable membrane mirror with high actuator density and distributed control (Oral Paper) <i>Roger Hamelinck, Nick Rosielle, Maarten Steinbuch, Rogier Ellenbroek, Michel Verhaegen and Niek Doelman</i>	35
Characterization and closed-loop demonstration of a novel electrostatic membrane mirror using COTS membranes (Oral Paper) <i>David Dayton, Justin Mansell, Bob and John Gonglewski</i>	41



Electrostatic micro-deformable mirror based on polymer materials (Oral Paper)	47
<i>Frederic Zamkotsian, Patrick Lanzoni, Veronique Conedera and Norbert Fabre</i>	
Recent progress in CMOS integrated MEMS AO mirror development (Oral Paper)	53
<i>A. Gehner, J. U. Schmidt, M. Wildenhahn, J. Knobbe and M. Wagner</i>	
Compact large-stroke piston-tip-tilt actuator and mirror (Oral Paper)	59
<i>W. Noell, A. Hugl, T. Overstolz, S. Waldis, R. Stanley and N. F. de Rooij</i>	
MEMS deformable mirrors for high performance AO applications (Oral Paper)	65
<i>Paul Bierden, Thomas Bifano and Steven Cornelissen</i>	
A versatile interferometric test-rig for the investigation and evaluation of ophthalmic AO systems (Poster Paper)	71
<i>Steve Gruppetta, Jiang Jian Zhong and Luis Diaz-Santana</i>	
Woofers-tweeters adaptive optics (Poster Paper)	77
<i>Thomas Farrell and Chris Dainty</i>	
Deformable mirrors based on transversal piezoeffect (Poster Paper)	83
<i>Gleb Vdovin, Mikhail Loktev and Oleg Soloviev</i>	
Low-cost spatial light modulators for ophthalmic applications (Poster Paper)	89
<i>Vicente Durán, Vicent Climent, Enrique Tajahuerce, Jesus Lancis, Zbigniew Jaroszewicz, Justo Arines, Jorge Ares, and Salvador Bará</i>	
Latest MEMS DM developments and the path ahead at Iris AO (Poster Paper)	95
<i>Michael A. Helmbrecht, Nathan Doble, Carl Kempf and Min He</i>	
Electrostatic push pull mirror improvements in visual optics (Poster Paper)	101
<i>S. Bonora and L. Poletto</i>	
25cm bimorph mirror for petawatt laser	106
<i>S. Bonora, C J Hooker, S. J. Hawkes, J. L. Collier and C. Spindloe</i>	



Hysteresis compensation for piezo deformable mirror (Poster Paper) <i>H. Song, R. Fraanje, G. Schitter, M. Verhaegen and G. Vdovin</i>	112
Static and dynamic responses of an adaptive optics ferrofluidic mirror (Poster Paper) <i>A. Seaman, C.J Cookson, J.B. Macpherson, E.F. Borra, A.M. Ritcey, D. Asselin, H. Jerominek, S. Thibault and M.C.W. Campbell</i>	118
New HDTV (1920 x 1080) phase-only SLM (Poster Paper) <i>Stefan Osten and Sven Krueger</i>	124
Monomorph large aperture deformable mirror for laser applications (Poster Paper) <i>J-C Sinquin, J-M Lurçon, C Guillemard</i>	130
Low cost, high speed for adaptive optics control (Oral Paper) <i>Christopher D. Saunter and Gordon D. Love</i>	136
Open loop woofer-tweeter adaptive control on the LAO multi-conjugate adaptive optics testbed (Oral Paper) <i>Edward Laag, Don Gavel and Mark Ammons</i>	143

## **Part 2 Wavefront Sensors**

Wave front sensorless adaptive optics for imaging and microscopy (Invited Paper) <i>Martin J Booth, Delphine Débarre and Tony Wilson</i>	151
A fundamental limit for wavefront sensing (Oral Paper) <i>Carl Paterson</i>	157
Coherent fibre-bundle wavefront sensor (Oral Paper) <i>Brian Vohnsen, I. Iglesias and Pablo Artal</i>	163
Maximum-likelihood methods in wave-front sensing: nuisance parameters (Oral Paper) <i>David Lara, Harrison H. Barrett, and Chris Dainty</i>	169
Real-time wavefront sensing for ultrafast high-power laser beams (Oral Paper) <i>Juan M. Bueno, Brian Vohnsen, Pedro M. Prieto, Luis Roso and Pablo Artal</i>	175

Wavefront sensing using a random phase screen (Oral Paper) <i>M. Loktev, G. Vdovin and O. Soloviev</i>	182
Quadri-Wave Lateral Shearing Interferometry: a new mature technique for wave front sensing in adaptive optics (Oral Paper) <i>Benoit Wattellier, Ivan Doudet, Sabrina Velghe and Jérôme Primot</i>	188
<i>In vivo</i> measurement of ocular aberrations with a distorted grating wavefront sensor (Oral Paper) <i>P Harrison, DM Cuevas, GRG Erry, P Fournier, L Diaz-Santana and C Torti</i>	193
Position-sensitive detector designed with unusual CMOS layout strategies for a Hartman-Shack wavefront sensor (Oral Paper) <i>Davies W. de Lima Monteiro, Luciana P. Salles, Pedro Retes, André S. O. Furtado and Gleb Vdovin</i>	200
Adaptive Optics system to compensate complex-shaped wavefronts (Oral Paper) <i>Miguel Ares, and Santiago Royo</i>	206
A kind of novel linear phase retrieval wavefront sensor and its application in close-loop adaptive optics system (Oral Paper) <i>Xinyang Li, Min Li, Bo Chen, Wenhan Jiang</i>	212
Ophthalmic Shack-Hatmann wavefront sensor applications (Oral Paper) <i>Daniel R. Neal</i>	219
Wave front sensing of an optical vortex and its correction with the help of bimorph mirror (Poster Paper) <i>F.A. Starikov, G.G. Kochemasov, S.M. Kulikov, A.N. Manachinsky, A.V. Ogorodnikov, S.A. Sukharev, V.P. Aksenov, I.V. Izmailov, F.Yu. Kanev, V. Atuchin and I. Soldatenkov</i>	227
Recent advances in laser metrology and correction of high numerical aperture laser beams using quadri-wave lateral shearing-interferometry (Poster Paper) <i>Benoit Wattellier, Ivan Doudet and William Boucher</i>	234
Thin film optical metrology using principles of wavefront sensing and interference (Poster Paper) <i>D.M. Faichnie, A.H. Greenaway and I. Bain</i>	237

Direct diffractive image simulation (Poster Paper)	243
<i>A.P. Maryasov, N.P. Maryasov, A.P. Layko</i>	
High speed smart CMOS sensor for adaptive optics (Poster Paper)	248
<i>T.D. Raymond, D.R. Neal, A. Whitehead, and G. Wirth</i>	
Traceable astigmatism measurements for wavefront sensors (Poster Paper)	254
<i>S R G Hall, S D Knox, R F Stevens</i>	

### **Part 3 Adaptive Optics in Vision Science**

Dual-conjugate adaptive optics instrument for wide-field retinal imaging (Oral Paper)	263
<i>Jörgen Thaug, Mette-Owner Petersen and Zoran Popovic</i>	
Visual simulation using electromagnetic adaptive-optics (Oral Paper)	269
<i>Laurent Vabre, Fabrice Harms, Nicolas Chateau, Karolinne Maia Rocha, Ronald Krueger</i>	
High-resolution field-of-view widening in human eye retina imaging (Oral Paper)	275
<i>Alexander V. Dubinin, Tatyana Yu. Cherezova, Alexis V. Kudryashov</i>	
Psychophysical experiments on visual performance with an ocular adaptive optics system (Oral Paper)	281
<i>E. Dalimier, J.C. Dainty and J. Barbur</i>	
Does the accommodative mechanism of the eye calibrate itself using aberration dynamics? (Oral Paper)	287
<i>K. M. Hampson, S. S. Chin and E. A. H. Mallen</i>	
A study of field aberrations in the human eye (Oral Paper)	293
<i>Alexander V. Goncharov, Maciej Nowakowski, Eugénie Dalimier, Matt Sheehan, and Chris Dainty</i>	
Dual wavefront corrector ophthalmic adaptive optics: design and alignment (Oral Paper)	299
<i>Alfredo Dubra and David Williams</i>	

High speed simultaneous SLO/OCT imaging of the human retina with adaptive optics (Oral Paper)	304
<i>M. Pircher, R.J. Zawadzki, J.W. Evans, J.S. Werner and C.K. Hitzenberger</i>	
Characterization of an AO-OCT system (Oral Paper)	310
<i>Julia W. Evans, Robert J. Zawadzki, Steve Jones, Scot Oliver, John S. Werner</i>	
Adaptive optics optical coherence tomography for retina imaging (Oral Paper)	316
<i>Guohua Shi, Zhihua Ding, Yun Dai, Xunjun Rao, Yudong Zhang</i>	
Development, calibration and performance of an electromagnetic-mirror-based adaptive optics system for visual optics (Oral Paper)	322
<i>Enrique Gamba, Lucie Sawides, Carlos Dorronsoro, Lourdes Llorente and Susana Marcos</i>	
Adaptive eye model (Poster Paper)	329
<i>Sergey O. Galetskiy and Alexey V. Kudryashov</i>	
Adaptive optics system for retinal imaging based on a pyramid wavefront sensor (Poster Paper)	336
<i>Sabine Chiesa, Elizabeth Daly, Chris Dainty and S.R. Chamot</i>	
Modeling of non-stationary dynamic ocular aberrations (Poster Paper)	342
<i>Conor Leahy and Chris Dainty</i>	
High-order aberrations and accommodation of human eye (Poster Paper)	348
<i>Lixia Xue, Yun Dai, Xuejun Rao, Cheng Wang, Yiyun Hu, Qian Liu and Wenhan Jiang</i>	
Electromagnetic deformable mirror: experimental assessment and first ophthalmic applications (Poster Paper)	354
<i>L. Vabre, E.J. Fernandez, F. Harms, J. Charton, B. Hermann, A. Unterhuber, B. Považay, N. Chateau and W. Drexler</i>	
Correcting ocular aberrations in optical coherence tomography (Poster Paper)	359
<i>Simon Tuohy, Adrian Bradu, Adrian Gh. Podoleanu, Nicolas Chateau and Chris Dainty</i>	

## Part 4 Adaptive Optics in Optical Storage and Microscopy

The application of liquid crystal aberration compensator for the optical disc systems (Invited Paper) <i>Masakazu Ogasawara</i>	369
Commercialization of the adaptive scanning optical microscope (ASOM) (Oral Paper) <i>Benjamin Potsaid, John T. Wen, Scott Barry and Alex Cable</i>	376
A practical implementation of adaptive optics for aberration compensation in optical microscopy (Oral Paper) <i>A J Wright, S P Poland, J Vijverberg, J M Girkin</i>	382
Active focus locking in an optically sectioning microscope using adaptive optics (Poster Paper) <i>S Poland, A J Wright, J M Girkin</i>	388
Towards four dimensional particle tracking for biological applications <i>Heather I. Campbell, Paul A. Dalgarno, Aurelie Putoud, Robert Lambert, Carola C. Diez, Alan Baird, Scott G. Aitken, David P. Towers, Richard J. Warburton and Alan H. Greenaway</i>	394
Adaptive optics for microscopy (Poster Paper) <i>Xavier Levecq</i>	400

## Part 5 Adaptive Optics in Lasers

Improved Beam Quality of a High Power Yb:YAG Laser (Oral Paper) <i>Dennis G. Harris, Falgun D. Patel, Charles E. Turner, Jr. and Michael M. Johnson</i>	407
Intracavity adaptive optics optimization of an end-pumped Nd:YVO4 laser (Oral Paper) <i>Petra Welp, Ulrich Wittrock</i>	413
New results in high power lasers beam correction (Oral Paper) <i>Alexis Kudryashov, Alex Alexandrov, Vadim Samarkin, Valentina Zavalova Alexey Rukosuev,</i>	419

Adaptive Optical Systems for the Shenguang-III Prototype Facility (Oral Paper)	426
<i>Zeping Yang, Chunlin Guan, Mingwu Ao, Ende Li, Muwen Fan, Ningping Shi, Yudong Zhang, Wenhan Jiang</i>	
Adaptive optics control of solid-state lasers (Poster Paper)	433
<i>Walter Lubeigt, David Burns, Mike Griffith and Leslie Laycock</i>	
Gerchberg-Saxton algorithm for multimode beam reshaping (Poster Paper)	439
<i>Inna V. Ilyina, Tatyana Yu. Cherezova</i>	
New algorithm of combining for spatial coherent beams (Poster Paper)	445
<i>Ruofu Yang, Xiaojun Zhang, Feng Shen and Wenhan Jiang</i>	
Intracavity mode control of a solid-state laser using a 19-element deformable mirror (Poster Paper)	451
<i>Ping Yang, Wei Yang, Yuan Liu, Mingwu Ao, Shijie Hu, Bing Xu, Wenhan Jiang</i>	
 <b>Part 6 Adaptive Optics in Communication and Atmospheric Compensation</b>	
Fourier image sharpness sensor for laser communications (Oral Paper)	459
<i>Kristin N. Walker and Robert K. Tyson</i>	
Fast closed-loop adaptive optics system for imaging through strong turbulence layers (Oral Paper)	465
<i>Ivo Buske and Wolfgang Riede</i>	
Correction of wavefront aberrations and optical communication using aperture synthesis (Oral Paper)	471
<i>R.J. Eastwood, A.M. Johnson, C. Kölper and A.H. Greenaway</i>	
Adaptive optics system for a small telescope (Oral Paper)	477
<i>G. Vdovin, M. Loktev and O. Soloviev</i>	
Fast correction of atmospheric turbulence using a membrane deformable mirror (Poster Paper)	483
<i>Ivan Capraro, Stefano Bonora, Paolo Villoresi</i>	

Atmospheric turbulence measurements over a 3km horizontal path with a Shack-Hartmann wavefront sensor (Poster Paper)	489
--	-----

*Ruth Mackey, K Murphy and Chris Dainty*

Field-oriented wavefront sensor for laser guide stars (Poster Paper)	495
--	-----

*Lidija Bolbasova, Alexander Goncharov and Vladimir Lukin*



## **Part 1**

# **Wavefront Correctors and Control**

