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University of Miami, USA
State University of New York USA
University of Nevada, USA
Copernicus University, Poland

Goal

Development of optical and photonic technologies in biomedicine, in particular for the non-invasive assessment of the normal and pathological eye

Relevance

myopia
• Affects 50% of the population
• Causes for their development not well understood
• No treatment available
• New alternatives for correction

presbyopia
• Affects 100% of the population older than 50

Aberrations

Simpler case: defocus (myopia)
Aberrations
The eye suffers from aberrations of higher order than defocus

Wave aberration:
phase distortions at the pupil plane

Goal
Development of optical and photonic technologies
to understand presbyopia
to evaluate/improve Compensation methods

Laser Ray Tracing: Basic Concept
Aberrated wavefront

LRT Aberrometry
Causes of optical aberrations

- Corneal topography
- Alignment of ocular surfaces
- Gradient index distribution
- Tuning cornea/crystalline lens

Corneal aberrations
- Ray Tracing
- Elevation map

Purkinje Imaging System
- Visual Optics & Biophotonics Lab, Instituto de Optica, CSIC
- Rosales et al.

Corneal aberrations
- Barbero et al. 2003

HARTMANN-SHACK WAVEFRONT SENSOR
- Liang & Williams, JOSA A'998
- Moreno-Barriuso, Marcos, Burns & Navarro, OVS 2001

Hartmann-Shack
- BADAL
- CCD
- MICROLENS ARRAY
- SLD
- 676 nm

Visual Optics & Biophotonics Lab, Instituto de Optica, Garcia de la Cera et al.
Purkinje imaging system for Phakometry

Lens tilt/decentration

\[ P_I = E \beta \]
\[ P_{III} = F \beta + A \alpha + C_d \]
\[ P_{IV} = G \beta + B \alpha + D_d \]

Crystalline lens curvature. Changes with accommodation

Optical Coherence Tomography

OCT Images

GRIN-LRT

Institute of Optics - Madrid
Laser Ray Tracing for crystalline GRIN

HeNe 594nm Laser Ray Tracing for crystalline GRIN
CCD2
OR
Ray deflections (1)
Ray impacts (2)

De Castro, Barbero & Marcos, 2007

Individual eye modelling

Axial length/ACD
Corneal topography
Crystalline lens shape
Pupil/lens tilt & decentration

Sources of aberrations
Lens GRIN models
Test of treatments (IOLS, LASIK, CLs)

De Castro, Barbero & Marcos, 2007

Customized modelling of eyes with IOLs

Predicted
Centered IOL

Measured
IOL with tilt & dec.

IOL geometry, tilt & dec.

Rosales & Marcos, Optics Express 2008

From morphology to microscopic structures

Scheimpflug
OCT

In vivo confocal microscopy

Tervo & Moilanen, 2003

Structured Illumination microscopy (in vivo)

Structured Illumination microscopy

Reques et al.

1. Project a 1D sine-pattern onto the sample
2. Record a series of images at equidistant phases with a wide-field detector
3. Compute sectioned images

φ = 0
φ = π/2
φ = 3π/2

IOL geometry, tilt & dec.

Structured Illumination microscopy

Reques et al.
Some sample questions

Question 1.- What triggers myopia development? What is the role of ocular aberrations in myopia?

Chick model: Axial length

Garcia de la Cera, Rodríguez & Marcos, Vision Res. (2006)

Observations:
- Occluded eye: 0.12 ± 0.02 mm/day
- Untreated eye: 0.05 ± 0.03 mm/day

Myopic eyes are more degraded than normal eyes.

Optical quality improves with development.

Chick model: Refraction

Garcia de la Cera, Rodríguez & Marcos, Vision Res. (2006)

Observations:
- Occluded: -1.5 ± 0.09 D/day
- Non-occluded: -1.5 ± 0.2 D/day

Corneal LASIK

Marcos et al., IOVS (2001)

Myopic LASIK

Marcos et al., IOVS (2001)
TOTAL aberrations

Increase of TOTAL Spherical Aberration with LASIK

Increase of CORNEAL Spherical Aberration with LASIK

Why corneal spherical aberration / asphericity increases after standard LASIK?

“Computational surgery”

Experimental \(K_\alpha\) (PMMA)

 Marcos-Barriuso et al. IOVS (2001)

 Marcus et al. IOVS (2001)

 Marcos et al. IOVS (2001)

 Marcos et al. IOVS (2001)

 Marcus at al. IOVS (2001)

 Marcos et al. IOVS (2001)


Corneal asphericities

Corneal biomechanical properties

Comparison with visual performance

Comparison with visual performance

Question 3. Can we improve optical quality of patients after cataract surgery with new intraocular lens designs?

Total, corneal & internal aberrations

POST CATARACT surgery
**Corneal aberrations**

- Pre-op
- Post-op
- Induced

Marcos et al. JCRS 2006

$\Phi=10$ mm, centered at corneal reflex

**Spherical aberration. Spherical/Aspheric**

<table>
<thead>
<tr>
<th>Spherical IOL</th>
<th>Aspheric IOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eye #</td>
<td>Eye #</td>
</tr>
<tr>
<td>Total</td>
<td>Corneal</td>
</tr>
<tr>
<td>IO Internal</td>
<td></td>
</tr>
</tbody>
</table>

Barbero et al. JOA (2003)


**Close loop adaptive optics correction**

- Close loop adaptive optics correction
- AO loop
- Correct wavefront using deformable optics
- Calculate control parameters
- Calculate residual wavefront using a sensor

**AO-correction of ocular aberrations**

- Wavefront
- PSF
- AO-correction of ocular aberrations

Gambra, Sawides & Marcos, 2007

**Adaptive optics system**

- Adaptive optics system
- Shack-Hartmann wavefront sensor
- Deformable mirror
- SLD : 826 nm

Sawides, Gambra & Marcos, 2007

**Question 4. Can we improve vision by correcting ocular aberrations?**

Deformable mirror

Eye

Badal System

SLD : 826 nm

Imagine Eyes 32 x 32 microlenses

Imagine Eyes MIRAO52d 52 actuators

$50 \mu m$ stroke

Sawides, Gambra & Marcos, 2007
Visual acuity after correction of ocular aberrations

- Natural aberrations
- Improvement at all luminances
- Increase of VA with luminance is primarily neural

Subject LS
Pupil=6 mm

Influence of the ocular aberrations on accommodation

Overview

Aberrometry
Optical biometry
High resolution imaging
Psychophysical tools
In vitro models
Measurement on patients
Animal models
Computer eye models

Outreach

Basic Science Training
Technology development
Industrial Impact
Clinical impact

Oportunidades de Becas/Contratos

- Opciones de solicitud de becas (FPU, FPI, JAEpre)
- Contratos con cargo a proyecto

http://www.vision.csic.es