On the possibility of adaptive optics for human vision

G. Vdovin, A. Naumov, M. Loktev
Electronic Instrumentation, TU Delft
Mekelweg 4, 2628 CD Delft, The Netherlands

gleb@ei.et.tudelft.nl
Adaptive optics technology

AO technology deals with real-time correction of optical aberrations. Used mainly in research environment. Established applications:
- Astronomy;
- Ophthalmology.
Micromachined Membrane Deformable Mirrors

The shape of tensed membrane is controlled by the electrostatic attraction to the grid of electrodes.

5th wavefront congress, Whistler, 2004
## Technical data

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam diameter</td>
<td>10 to 30mm</td>
</tr>
<tr>
<td>Wavelength</td>
<td>250nm to 5um</td>
</tr>
<tr>
<td>Optical power</td>
<td>up to 500W</td>
</tr>
<tr>
<td>Response time</td>
<td>0.5ms</td>
</tr>
<tr>
<td>Power consumption</td>
<td>1W</td>
</tr>
<tr>
<td>Deflection range</td>
<td>30um</td>
</tr>
<tr>
<td>Actuators range</td>
<td>1 to 79 actuators</td>
</tr>
<tr>
<td>Design</td>
<td>Rugged design</td>
</tr>
<tr>
<td>Usage</td>
<td>Can work inside</td>
</tr>
<tr>
<td></td>
<td>The cavity</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>up to 99.9%</td>
</tr>
</tbody>
</table>
How it moves

5th wavefront congress, Whistler, 2004
Thermal and piezoelectric mirrors

Thermal deformable mirror: www.okotech.com
Linear deformable mirror: www.okotech.com

5th wavefront congress, Whistler, 2004
SVD decomposition in a feedback loop

![Diagram of optical setup with reference, beam splitter, deformable mirror, imaging system, Hartmann mask, CCD, and control PC (Linux) 19x8bit DAC + drivers.]

![Graph showing singular values (normalized) with control options to ignore modes with singular values < 0.01 or higher than 34.]

5th wavefront congress, Whistler, 2004
Modes of the system
Correction quality

1. Defocus (Z[2,0]), amplitude 1 mic

2. Astigmatism (Z[2,1]), amplitude 1 mic

3. Cornea (Z[3,1]), amplitude 1 mic

---

5th wavefront congress, Whistler, 2004
Solar telescope
• Ideal corrector uses Karhunen-Loeve functions
• Ideal corrector does not exist
• Zernike polynomials represent a good approach to Karhunen-Loeve functions for atmospheric statistics of aberrations (human eye ??)
• Each deformable mirror has its own basis of orthogonal functions which is different from Zernike basis
• In case of adaptive correction, Zernike polynomials are irrelevant for the feedback loop but are relevant for presentation of results
Deformable mirrors

- Continuous faceplate
- Bimorph
- Membrane
- Micromachined membrane
- Surface micromachined
- Piston-type
- $N_{kl} = N_{act}/1.5 \ldots N_{act}/5$
AO for the eye

5th wavefront congress, Whistler, 2004
Ophthalmic AO system

The system (University of Murcia) shown uses MMDM. The system was used for HR retinal imaging.
Adaptive spectacles

• AO is applicable to the human eye and can increase the optical resolution
• AO should be **conjugated** to the eye lens, resulting in bulky and complicated setups

• The only way to use AO for everyday vision correction is the incorporation of the AO within the human eye
• There are two ways to incorporate the AO: a contact lens and an intra-ocular implant
Goals:

1. Restoration of the accommodation ability of the human eye for two target groups: with artificial eye implant and for elderly people (a contact lens)

2. Improvement of the visual acuity over the natural limit (to be researched).
Approach

Spectacle lens

Adaptive eye lens

Control link
Requirements to the implant

- Safe (low power low voltage);
- Small and bio-compatible, chemically neutral;
- Wireless control and feedback (HOW??);
- Temporal stability;
- Transparent;
- Polarization insensitive;
- Usable with the control system off;
- Transparent for oxygen (contact lens only).
Adaptive LC correctors: small (5 to 10 mm), low power (less than 1 mv), safe, non-toxic, transparent (90%), usable with power off (no focusing power), durable.
Adaptive LC lens
LC lenses

- Low power, durable, backed by a long established technology (LC displays and indicators)
- Low power consumption, low control voltage
- Non toxic
- Can correct defocus, spherical aberration and higher order radial terms
- Can be designed to correct low-order Zernike terms
- Dispersion is opposite to the eye’s dispersion! – corrector of chromatic aberration.
- Slow response, polarization sensitive
Suggested implant configuration

- Integrated receiver coil;
- Integrated LC lens
- Encapsulation: same as for ocular implants;
- Focusing power controlled by the amplitude and frequency of the control signal
- With no control acts as a static implant
Control approaches

- Inductive link with primary coil in the frame of the spectacles
- Capacitive link with the control plate deposited onto the spectacle glass
- Optical link with array of photodiodes integrated into the implant
Inductive link (ignition coil)

\[ E = \frac{LI^2}{2} = \frac{CU^2}{2} \]

\[ U_{\text{max}} = \sqrt{\frac{LI^2}{C}} ; \quad U_{\text{LENS}} = \frac{S^2}{S_1} U_{\text{max}} \]
Driver schematic

+V = ~140v

Stop
Start

100k

2.2k

+8v

1uF

R_Lim

RF Choke

100uH

Resonant Coil

Feedback loop

TPS2814P

gate driver

STP3NB80 MOSFET
Technical goals:

- Development of a multi-channel wireless link to the implantable adaptive corrector;
- Development of the packaging approach for a LC corrector, both for the contact lens implementation and for the implant;
- Development of a wireless-powered and controlled “smart” adaptive optical component.

The technical goals are feasible in a wider sense than the final application-specific goals. They are in the streamline of the general development of the AO technology.
First results

- LC lenses with aperture 6 mm, range of 3D and response time of 0.5 s are readily available.
- First experiments with wireless electromagnetic control were successful, the driver is bulky and not integrated yet.
- Polarization insensitive and multichannel versions under development
- Feedback control is a problem to solve.
Conclusions

• LC lens can be usable for ocular correction
• LC lens can be remotely wirelessly controlled with a low-power unit
• The final research goal is risky, although the technical problems to be solved are sound, realistic and the results will be usable for a broader range of “smart optics” applications.
• Got funding from the Dutch Technical Foundation