Optical Fabrication, Testing, and Metrology III

Angela Duparré
Roland Geyl
Editors

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Jacques Mangin, Université de Bourgogne (France)

Optical system design reliance on technology development

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WELCOME

Firstly, thanks goes to SPIE, the organizing committee, Chairs and Co-Chairs of the Conference for acceptance of this presentation

INTRODUCTION

Before commencing with an outline of the presentation an explanation of the the definitions used throughout is given

"Optical system design reliance on technology development" ScotOptix

DEFINITIONS

1. Technology development is the progression over time of manufactured optical components:
   - Materials ≈ optical substrates
   - Coatings ≈ multi-layer thin films
   - Surfaces ≈ optical surface profiles
2. Optical design software is a tool to apply technology
3. Optical designer 'creates' the optics portion of the of the optical system design utilizing optical design software to apply technology
4. FOV is Field of View & NA is Numerical Aperture

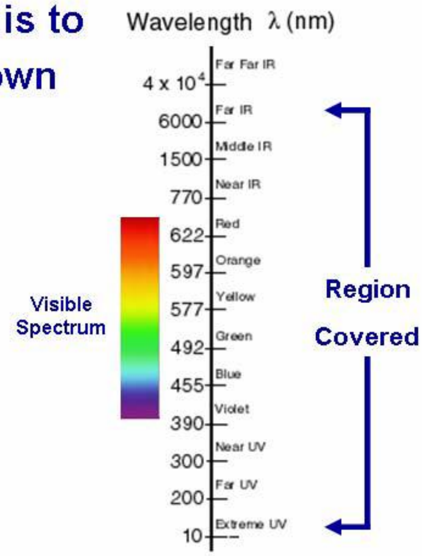
"Optical system design reliance on technology development" **ScotOptix**

DEFINITIONS (Cont'd)

❺ Object is to the left and Image is to the right unless otherwise shown

❻ Three wavebands discussed:

- Infrared ≈ 0.7-1.5, 3-5 & 8-13μm
  (700-1500, 3000-5000 & 8000-13000nm)
- Visible ≈ 0.435-0.656μm
  (435-656nm)
- Ultraviolet ≈ 0.434~0.013μm
  (434.4-13.4nm)



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"Optical system design reliance on technology development" **ScotOptix**

OUTLINE

- By way of mainly the US Patent database, examples are given to illustrate the reliance of optical system design on key technology
- The examples are categorized by waveband of operation and partly chronologically
- Performance characteristics are not discussed but all examples may be considered high performance for their intended applications

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WAVEBAND 1
INFRARED

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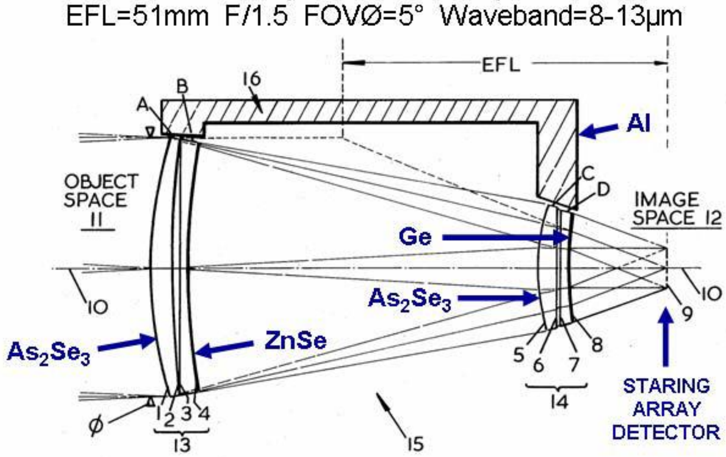
EXAMPLE 1.1
PETZVAL OBJECTIVE – SECURITY

Passively Athermalized System
EFL=51mm F/1.5 FOVØ=5° Waveband=8-13μm

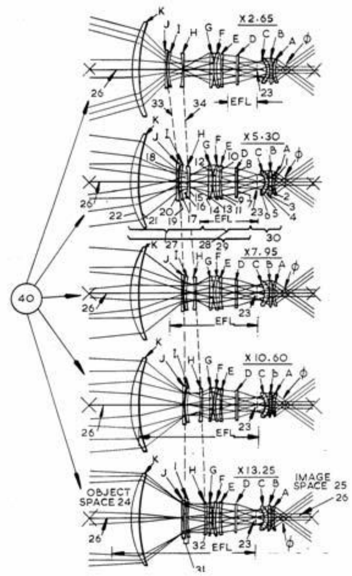


KEY TECHNOLOGY	
✓	MATERIAL
	COATING
	SURFACE
BENEFITS	
SOLID STATE	
ROBUST	
ISSUES	
TOXIC MATERIAL	
MATERIAL QUALITY	

US Pat. No. 4,505,535 A1 I.A.Neil Mar. 19, 1985

EXAMPLE 1.2a

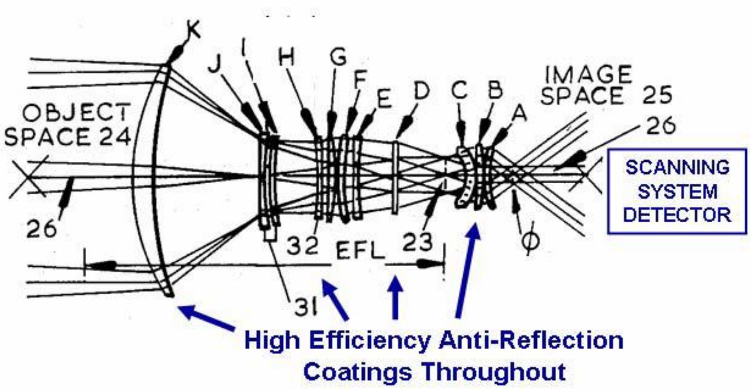
ZOOM TELESCOPE – SECURITY



EXAMPLE 1.2b

ZOOM TELESCOPE – SECURITY

Compact Mechanically Compensated Zoom System
Zoom Ratio=5x Exit Pupil Ø=10mm & FOVØ=72° Waveband=8-13µm

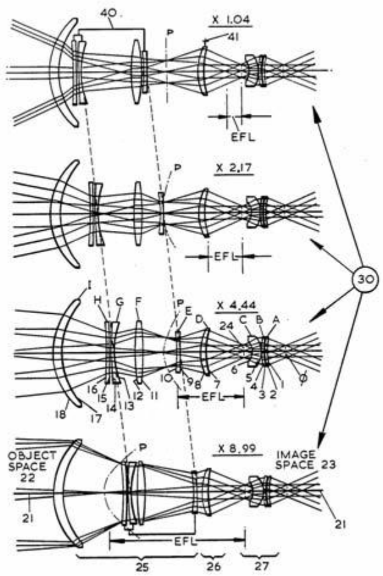


KEY TECHNOLOGY	
	MATERIAL
✔	COATING
	SURFACE
BENEFITS	
COMPACT	
ISSUES	
NONE	

US Pat. No. US4,659,171 A1 I.A.Neil Apr. 21, 1987

EXAMPLE 1.3a

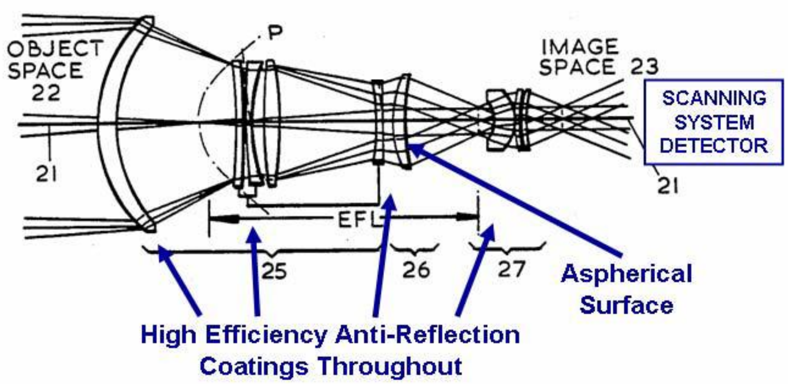
ZOOM TELESCOPE – SECURITY



EXAMPLE 1.3b

ZOOM TELESCOPE – SECURITY

Compact Optically Compensated Zoom System
Zoom Ratio=9x Exit Pupil Ø=14.4mm & FOVØ=60° Waveband=8-13µm



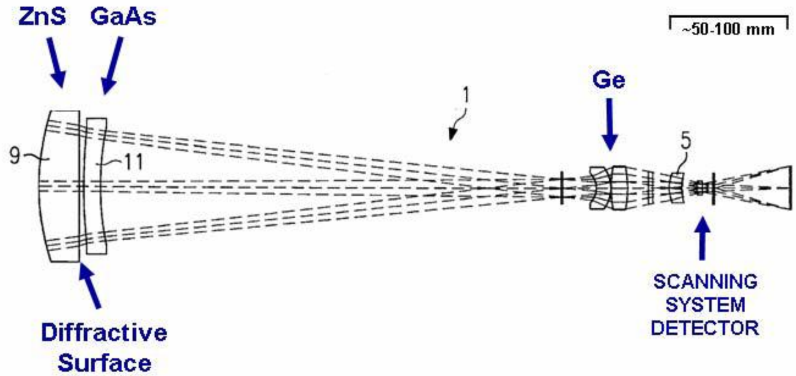
US Pat. No. 4,632,498 A1 I.A.Neil Dec. 30, 1986

KEY TECHNOLOGY	
	MATERIAL
✔	COATING
✔	SURFACE
BENEFITS	
COMPACT	
SIMPLE MECHANICS	
ISSUES	
FOCUS DRIFT THROUGH ZOOM	
ASPHERE COST	

EXAMPLE 1.4

OBJECTIVE – SECURITY

Passively Athermalized & Color Corrected Air Spaced Doublet
with Diffractive Surface
Waveband=8-13μm (possibly 3-5μm depending on materials)

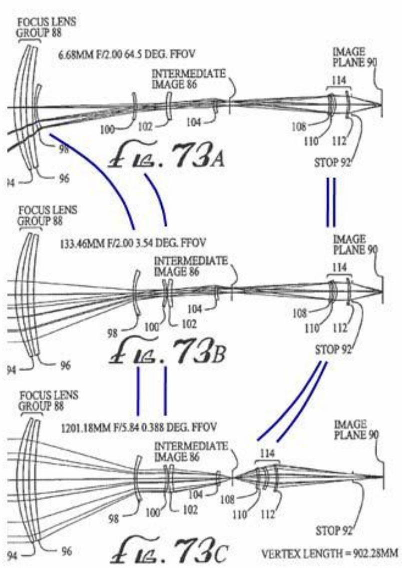


US Pat. No. 5,504,628 A1 J.F.Borchard Apr. 2, 1996

KEY TECHNOLOGY	
✓	MATERIAL
	COATING
✓	SURFACE
BENEFITS	
SOLID STATE	
ROBUST	
ISSUES	
SECONDARY COLOR	
LONG LENGTH	

EXAMPLE 1.5a

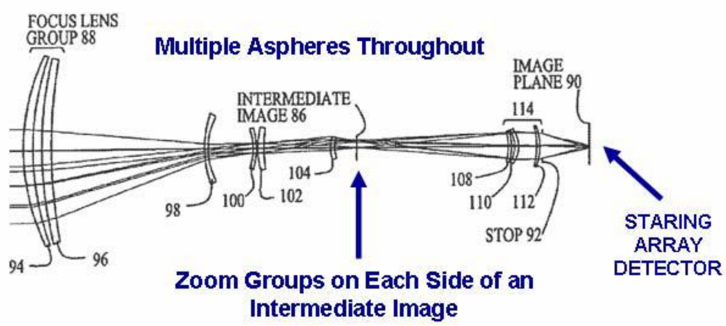
ZOOM OBJECTIVE – SECURITY



EXAMPLE 1.5b

ZOOM OBJECTIVE – SECURITY

Compound Zoom System
Zoom Ratio=180x EFL=6.7-1201mm F/2-5.84 FOVØ=64.5-0.4°
Wavebands=3-5µm or 8-13µm



KEY TECHNOLOGY	
	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
HIGH ZOOM RATIO	
ISSUES	
COMPLEX MECHANICS	
IMAGE F/NO VARIES	
ASPHERE COST	

US Pat. No. 7,224,535 B2 I.A.Neil May 29, 2007

WAVEBAND 2

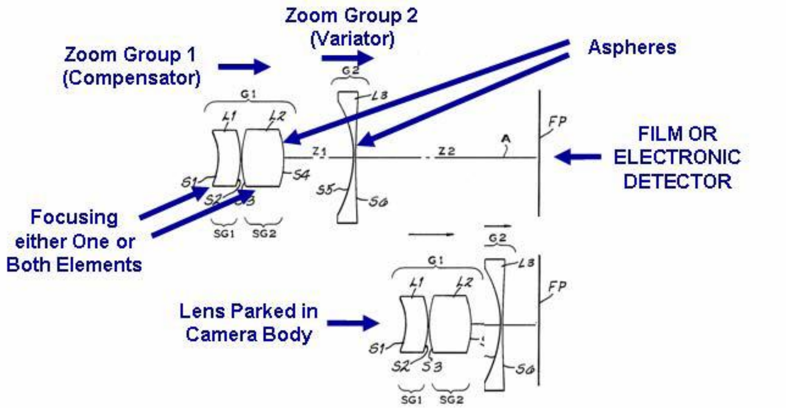
VISIBLE

EXAMPLE 2.1

COMPACT CAMERA ZOOM OBJECTIVE – PHOTOGRAPHIC CONSUMER

Zoom Objective System with 2x Zoom Ratio

EFL=35.7-68.5mm F/3.5-6.8 ImageØ=43.2mm Waveband=Visible



KEY TECHNOLOGY	
	MATERIAL
	COATING
✓	SURFACE
BENEFITS	
SIMPLE	
COMPACT	
LOW COST	
ISSUES	
MOLDED ASPHERES	

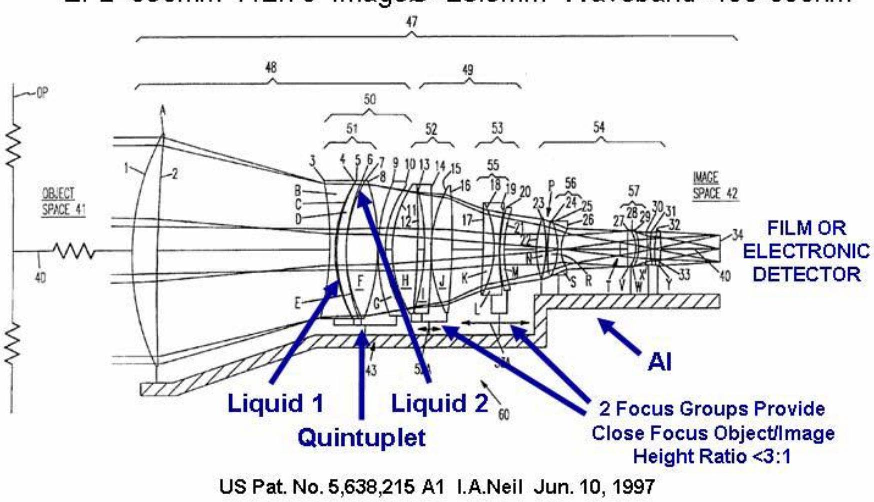
US Pat. No. 4,936,661 A1 E.I.Betensky, M.H.Kreitzer & J.Moskovich Jun. 26, 1990

EXAMPLE 2.2a

TELEPHOTO OBJECTIVE – PHOTOGRAPHIC CINE

Passively Athermalized & Color Corrected System with Liquid Elements

EFL=693mm F/2.75 ImageØ=28.9mm Waveband=435-656nm

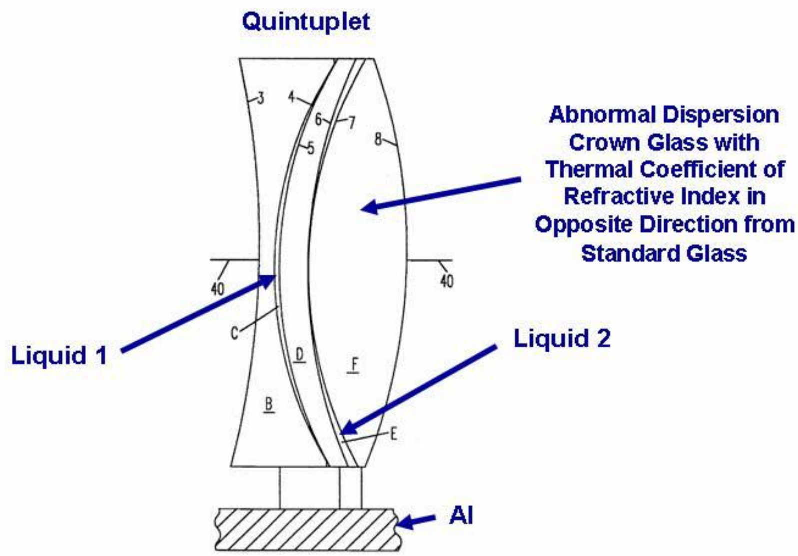


KEY TECHNOLOGY	
✓	MATERIAL
✓	COATING
	SURFACE
BENEFITS	
LOW COST GLASSES	
COMPACT	
ISSUES	
LIQUID DISCOLORATION	
LOW TEMPERATURE	

US Pat. No. 5,638,215 A1 I.A.Neil Jun. 10, 1997

EXAMPLE 2.2b

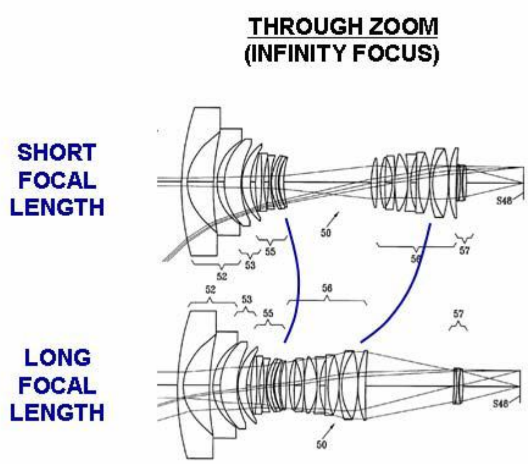
TELEPHOTO OBJECTIVE – PHOTOGRAPHIC CINE



"Optical system design reliance on technology development" ScotOptix

EXAMPLE 2.3a

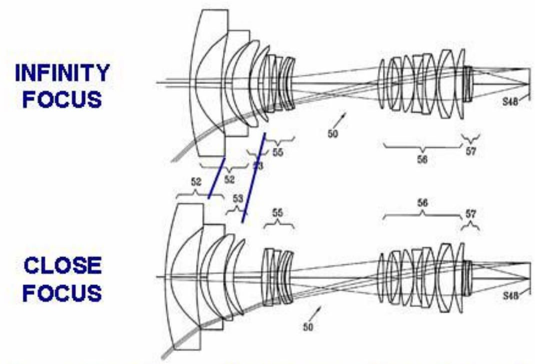
MACRO FOCUS ZOOM OBJECTIVE – PHOTOGRAPHIC CINE



EXAMPLE 2.3b

MACRO FOCUS ZOOM OBJECTIVE – PHOTOGRAPHIC CINE

THROUGH FOCUS
(SHORT FOCAL LENGTH)

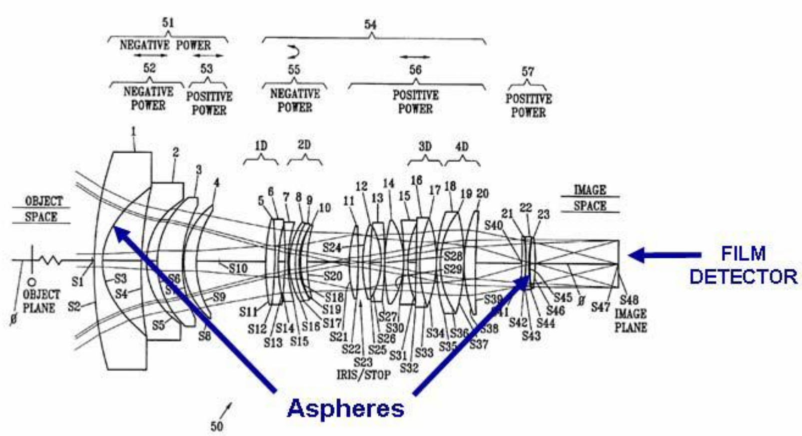


Close Focus Object/Image Height Ratio = 2.5:1 (At Long Focal Length)

EXAMPLE 2.3c

ZOOM OBJECTIVE – PHOTOGRAPHIC CINE

Macro Focus Zoom System with 3.5x Zoom Ratio
EFL=14.5-50mm F/2.2 ImageØ=28.9mm Waveband=455-644nm



KEY TECHNOLOGY	
	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
VERSATILE	
FIXED FOCAL LENGTH OPTION	
ISSUES	
COMPLEX MECHANICS	
ASPHERE COST	

US Pat. No. 6,122,111 A1 I.A.Neil & E.I.Betensky Sep. 19, 2000

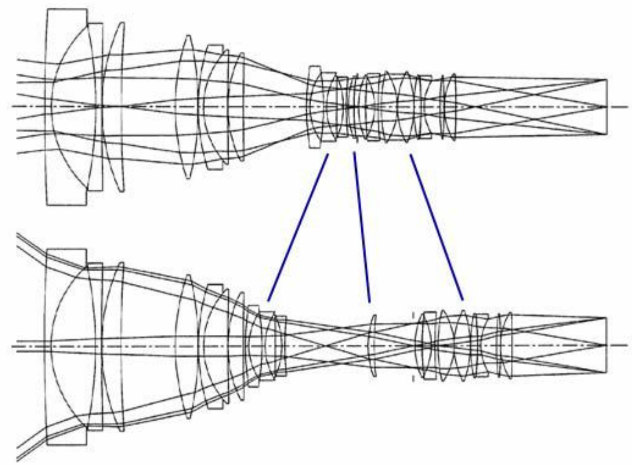
EXAMPLE 2.4a

ZOOM OBJECTIVE – PHOTOGRAPHIC CINE

THROUGH ZOOM
(INFINITY FOCUS)

LONG FOCAL LENGTH

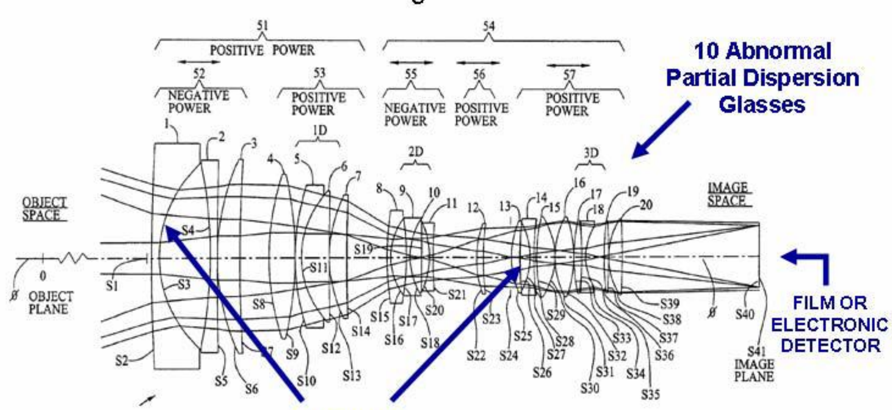
SHORT FOCAL LENGTH



EXAMPLE 2.4b

ZOOM OBJECTIVE – PHOTOGRAPHIC CINE

Compact Zoom Objective System with 4.7x Zoom Ratio
EFL=19-90mm F/2.7 ImageØ=27.8mm Waveband=455-644nm



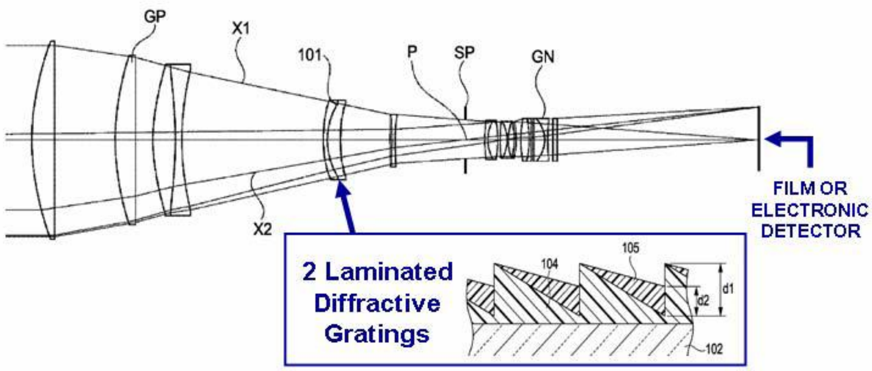
US Pat. No. 7,123,421 B1 J.Moskovich, I.A.Neil & T.Yamanashi Oct. 17, 2006

KEY TECHNOLOGY	
✓	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
COMPACT	
VERSATILE	
FIXED FOCAL LENGTH OPTION	
ISSUES	
COMPLEX MECHANICS	
ASPHERE COST	

EXAMPLE 2.5

OBJECTIVE – PHOTOGRAPHIC PROSUMER

Telephoto System with Diffractive Surface
EFL=780mm F/5.8 ImageØ=43.2mm Waveband=435-656nm



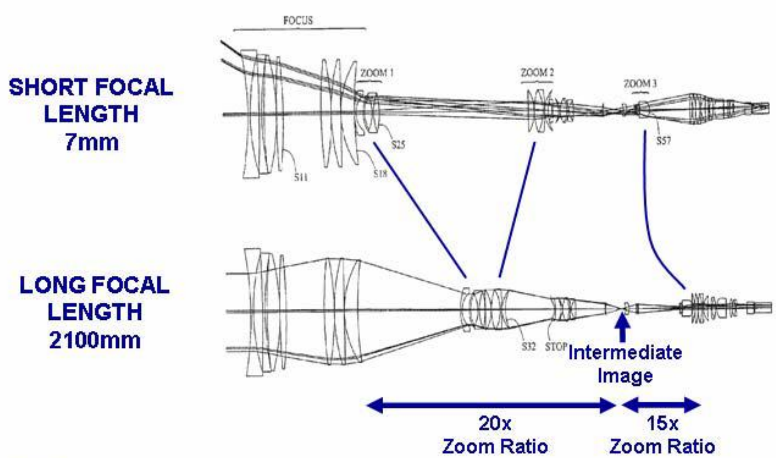
KEY TECHNOLOGY	
✓	MATERIAL
	COATING
✓	SURFACE
BENEFITS	
COMPACT	
COLOR CORRECTED	
REDUCED NO. OF EXOTIC GLASSES	
ISSUES	
FLARE	

US Pat. Pub. No. 2008/0088950 A1 H.Endo Apr. 17, 2008

EXAMPLE 2.6a

ZOOM OBJECTIVE – PHOTOGRAPHIC HDTV

THROUGH ZOOM (INFINITY FOCUS)



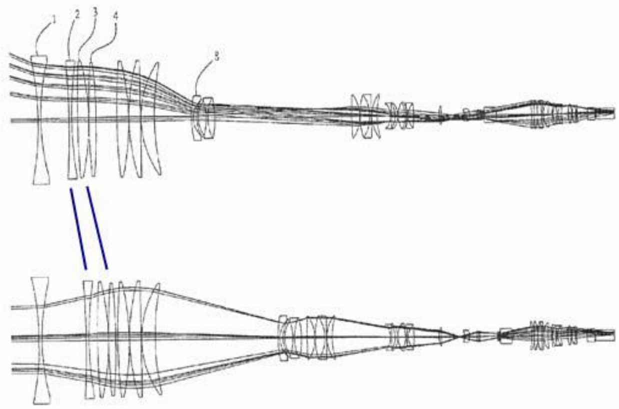
EXAMPLE 2.6b

ZOOM OBJECTIVE – PHOTOGRAPHIC HDTV

THROUGH FOCUS
(SHORT TO LONG FOCAL LENGTH)

SHORT FOCAL LENGTH CLOSE FOCUS

LONG FOCAL LENGTH INFINITY FOCUS



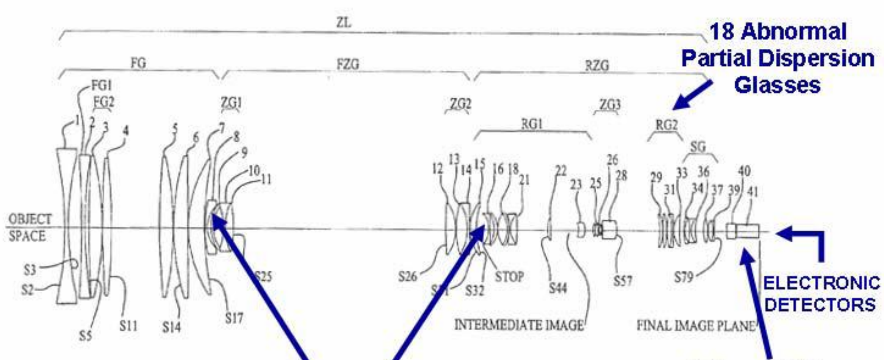
Close Focus Object/Image Height Ratio = 1.33:1 (At Long Focal Length)

"Optical system design reliance on technology development" ScotOptix

EXAMPLE 2.6c

ZOOM OBJECTIVE – PHOTOGRAPHIC HDTV

Compound Zoom System with 300x Zoom Ratio
EFL=7-2100mm F/2-13 ImageØ=11mm Waveband=Visible



KEY TECHNOLOGY	
✓	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
LARGE ZOOM RATIO	
VERSATILE	
ISSUES	
COMPLEX MECHANICS	
ASPHERE COST	

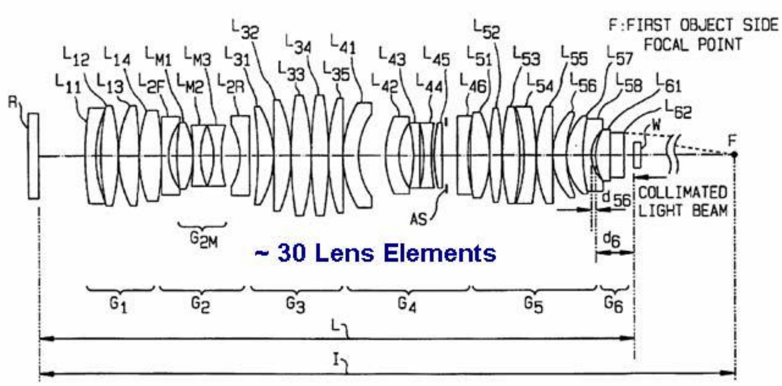
US Pat. No. 6,691,188 B2 E.I.Betensky, J.B.Caldwell, I.A.Neil & T.Yamanashi Nov. 1, 2005

WAVEBAND 3
ULTRAVIOLET

EXAMPLE 3.1
PROJECTION RELAY LENS – MICROLITHOGRAPHIC

All Refractive Projection System

RELAY=5:1 NA=0.57 ImageØ=31.2mm Wavelengths=193, 248 & 365nm



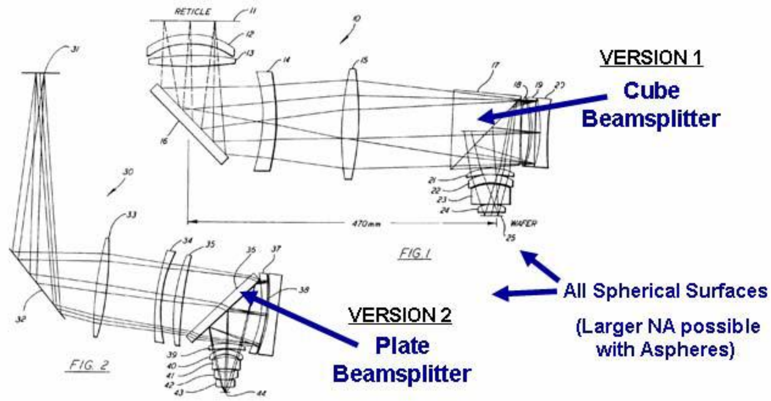
KEY TECHNOLOGY	
	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
RESOLUTION	
ISSUES	
INHOMOGENEITY & BIREFRINGENCE	
SURFACE QUALITY	
ALIGNMENT	

US Reissued Pat. No. RE 37,846E H.Matsuzawa, M.Kobayashi, K.Endo & Y.Suenaga Sep. 17, 2002

EXAMPLE 3.2

PROJECTION RELAY LENS – MICROLITHOGRAPHIC

Refractive/Reflective Projection System
RELAY=4:1 NA=0.45 ImageØ=30mm Wavelengths=240-256nm



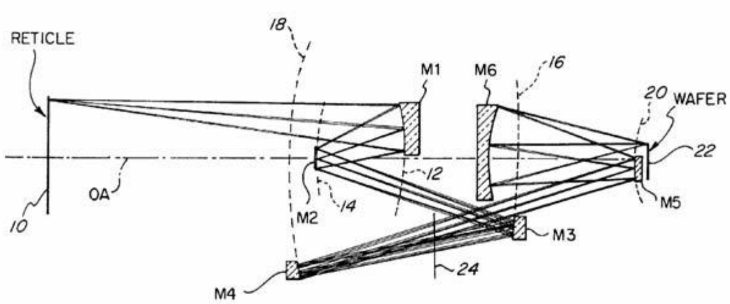
KEY TECHNOLOGY	
✓	MATERIAL
✓	COATING
	SURFACE
BENEFITS	
RESOLUTION	
ISSUES	
ALIGNMENT	

US Pat. No. 4,953,960 A1 D.M.Williamson Sep. 4, 1990

EXAMPLE 3.3

PROJECTION RELAY OPTICS – MICROLITHOGRAPHIC

All Reflective Projection System
RELAY=4:1 NA=0.25 ImageØ=31mm Wavelengths=13.4nm & <200nm



6 Mirrors with 6 Aspheres

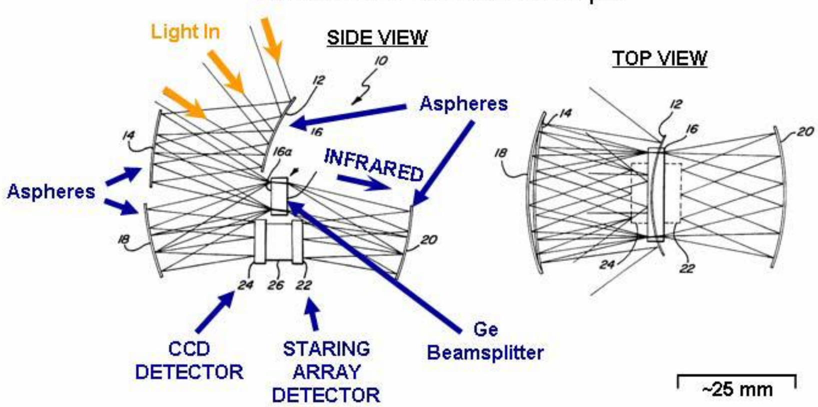
KEY TECHNOLOGY	
	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
HIGH RESOLUTION	
ISSUES	
@13.4nm <10% TRANSMISSION WITH COATINGS	
ASPHERE COST	
ALIGNMENT	

US Pat. No. 5,815,310 A1 D.M.Williamson Sep. 29, 1998

WAVEBAND 4
MULTIPLE

EXAMPLE 4.1
OBJECTIVE – SECURITY

Dual Waveband System
F/4.5(elev), F/1.5(azim) & F/2.3(average) FOVØ=40°(elev.) & 53°(azim.)
Wavebands=Visible & 8-13µm



KEY TECHNOLOGY	
	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
COMPACT	
SOLID STATE	
ROBUST	
ISSUES	
ASPHERE COST	

US Pat. No. 5.847,879 A1 L.G.Cook Dec. 8, 1998

EXAMPLE 4.2a

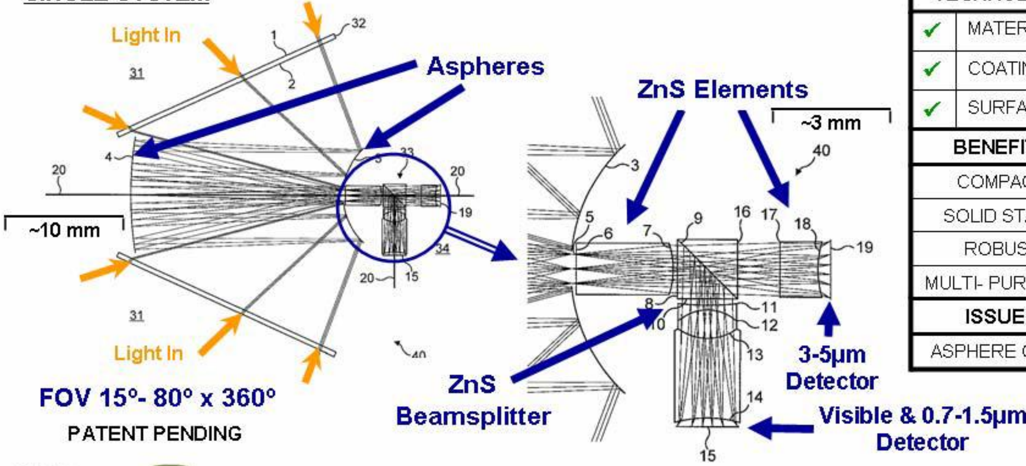
OBJECTIVE – SURVEILLANCE

Compact Multi-waveband Wide Angle Objective

FOV 15°- 80° x 360°

Wavebands=Visible, 0.7-1.5μm & 3-5μm

SINGLE SYSTEM



KEY TECHNOLOGY	
✓	MATERIAL
✓	COATING
✓	SURFACE
BENEFITS	
COMPACT	
SOLID STATE	
ROBUST	
MULTI- PURPOSE	
ISSUES	
ASPHERE COST	

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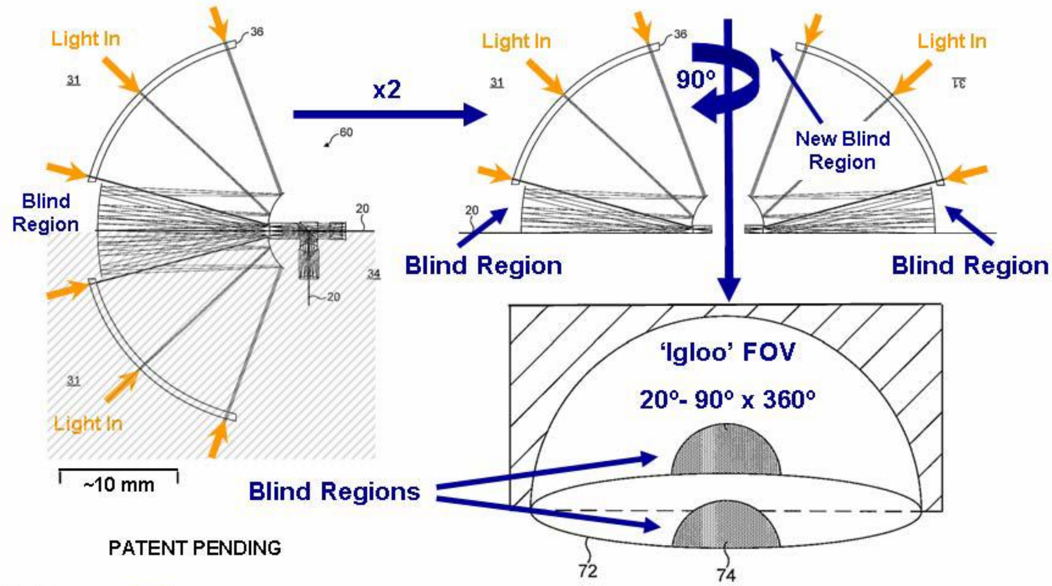
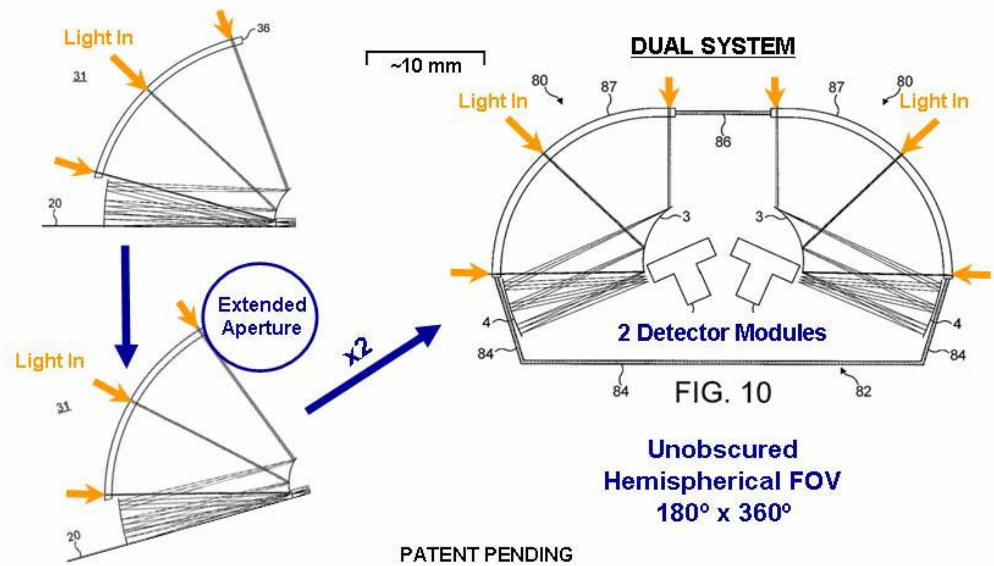
EXAMPLE 4.2b

OBJECTIVE – SURVEILLANCE



EXAMPLE 4.2c

OBJECTIVE – SURVEILLANCE



Unobscured Hemispherical FOV 180° x 360°

PATENT PENDING

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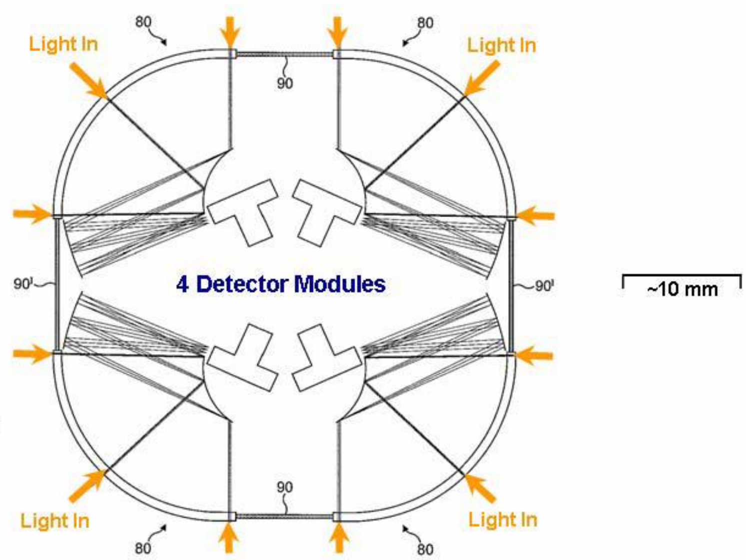
EXAMPLE 4.2d

OBJECTIVE – SURVEILLANCE

QUAD SYSTEM

Unobscured Global FOV 360° x 360°

PATENT PENDING



KEY TECHNOLOGY SUMMARY

	WAVEBAND															
	INFRARED					VISIBLE						ULTRAVIOLET			MULTI	
EXAMPLE	1.1	1.2	1.3	1.4	1.5	2.1	2.2	2.3	2.4	2.5	2.6	3.1	3.2	3.3	4.1	4.2
CIRCA	80's	80's	80's	90's	00's	90's	90's	00's	00's	00's	00's	90's	90's	90's	90's	00's
MATERIAL	✓			✓			✓		✓	✓	✓		✓			✓
COATING		✓	✓		✓		✓	✓	✓		✓	✓	✓	✓	✓	✓
SURFACE			✓	✓	✓	✓		✓	✓	✓	✓	✓		✓	✓	✓

"Optical system design reliance on technology development" ScotOptix

CONCLUSION

- Usually technology provides 'improvements' but occasionally it is 'disruptive' in that it dramatically changes the optical system design such as enabling a new form of design
- In the specific case of disruptive technology this usually appears to happen separately in either materials, coatings or surfaces
- No apparent trend in technology development except:

"Necessity is the mother of invention"

Plato c. 400 BC

ACKNOWLEDGEMENTS

Thanks goes to the following individuals for contributions to this presentation

David W. Samuelson

David M. Williamson

Andy Wood

A Perspective on the Design of Head-Worn Displays

Jannick Rolland with

Ozan Cakmakci, Florian Fournier, and Sophie Vo

CREOL, The College of Optics and Photonics
the University of Central Florida

http://odalab.ucf.edu
jannick@odalab.ucf.edu

Highlights

Introduction
- Applications
- Prior Work

Early work at ODALab

Current Technologies under Development
- Head-mounted Projection Displays (HMPD)
- Eyeglass Head-Worn Displays (HWD)

Why Head-Worn Displays?

Assuming HWDs can be designed aesthetically (which is not a given) to meet with social acceptance:

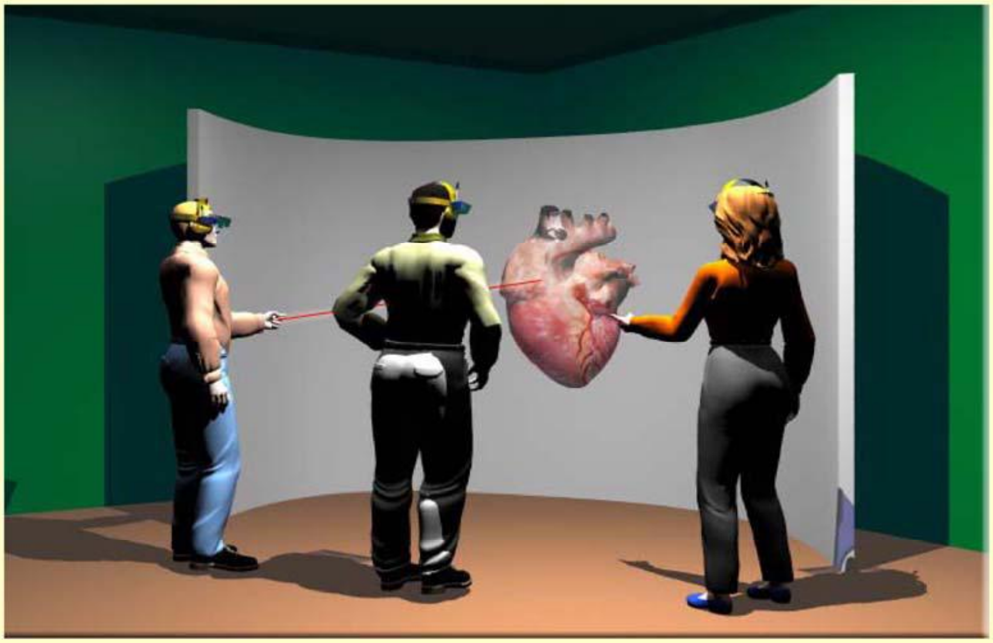
- **Mobility**
- **Privacy**

- **Constancy:** Provides the basis for novel user interfaces that are available constantly (on a demand basis) to the user

Science Fiction Sets Expectations of Where we Aim to Be Going!

* Goldsman, A. (1998). Lost in Space. New Line Cinema

Medical Rooms of the Future



Telemedicine: Face to Face Teleportal

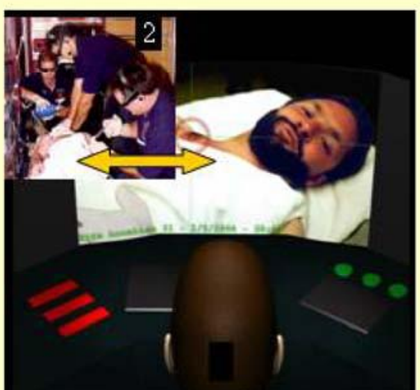


Fig 1. Vision of "see-thru-my-eyes" capability. (1) Doctor in local control room guides (2) remote treatment via stereoscopic see-thru headset worn by emergency technician.

Fig.2. Vision of mobile "Face-to-Face" interaction (1) remote team member wearing 3D face recording system talk in to (2) team leader in control center.

Courtesy of Frank Biocca, MSU

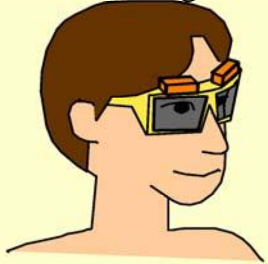
Wearable Displays:
A Range of Possibilities

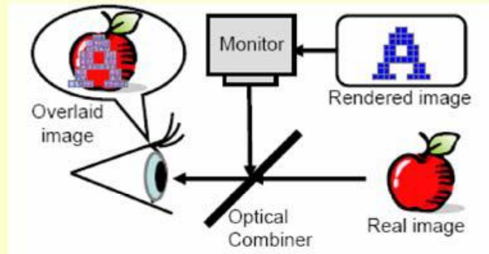
Their future lies in large part in their "seamless" integration with tangible interfaces around us

Augmented Reality
/ Mixed Reality
Vs. Virtual Reality (full immersion)

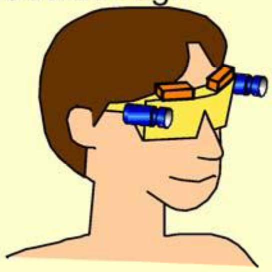
Augmented/Mixed Reality

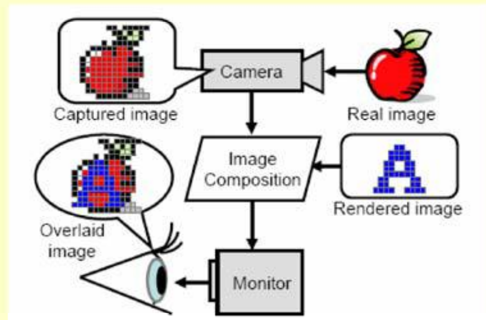
Optical See-through





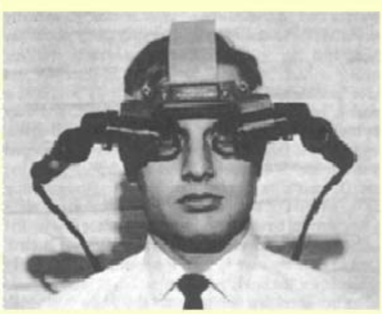
Video See-through

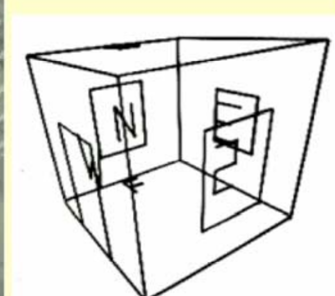




Historical Notes

First graphics-driven HWD was developed by Ivan Sutherland in the 1960s.

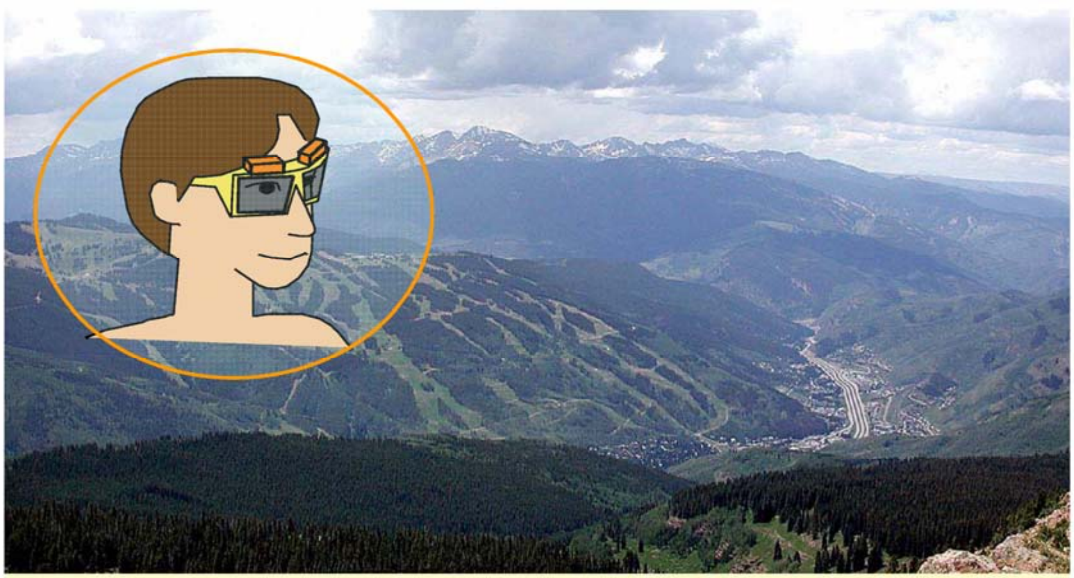




Augmented Reality Displays

Early (first?) stereoscopic VST-HMD

- HMD-mounted stereo cameras with custom-designed lenses compensate for display distortion (Biocca & Rolland, Presence 1998)



Some applications call for optical see-though capability

Highlights from Past Development

- U.S. Army first to fly a helmet-mounted sighting system on the Cobra helicopter.
- IHADSS (Integrated Helmet and Display Sighting System) was then deployed by the U.S. Army for the AH-64 Apache Helicopter.

IHADSS, while monocular, greatly contributed to the proliferation of all types of HMDs.

The success of HWD design is most likely to occur when developed

- In the context of the users and
- Targeted at specific applications

A Main Design Trade-off

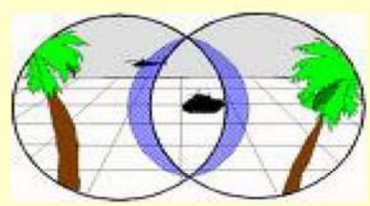
FOV vs. Resolution - Currently limited by microdisplays

Angle subtended by a pixel = $\frac{FOV}{\#\ of\ pixels}$ Human eye 1arcmin

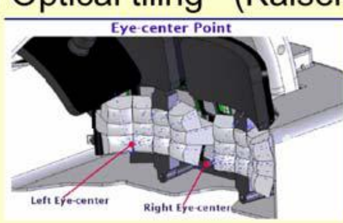
Approaches:

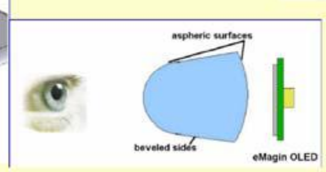
1) High-resolution area of interest or inset

2) Partial binocular overlap ("Luning")



3) Optical tiling (Kaiser, Sensics)





Recent developments by Sensics.

Driven by Medical Visualization: VRDA Tool "Virtual Reality Dynamic Anatomy"

NIH - First Award 1997-2002

Methods Optics, Computer Vision, and Graphics

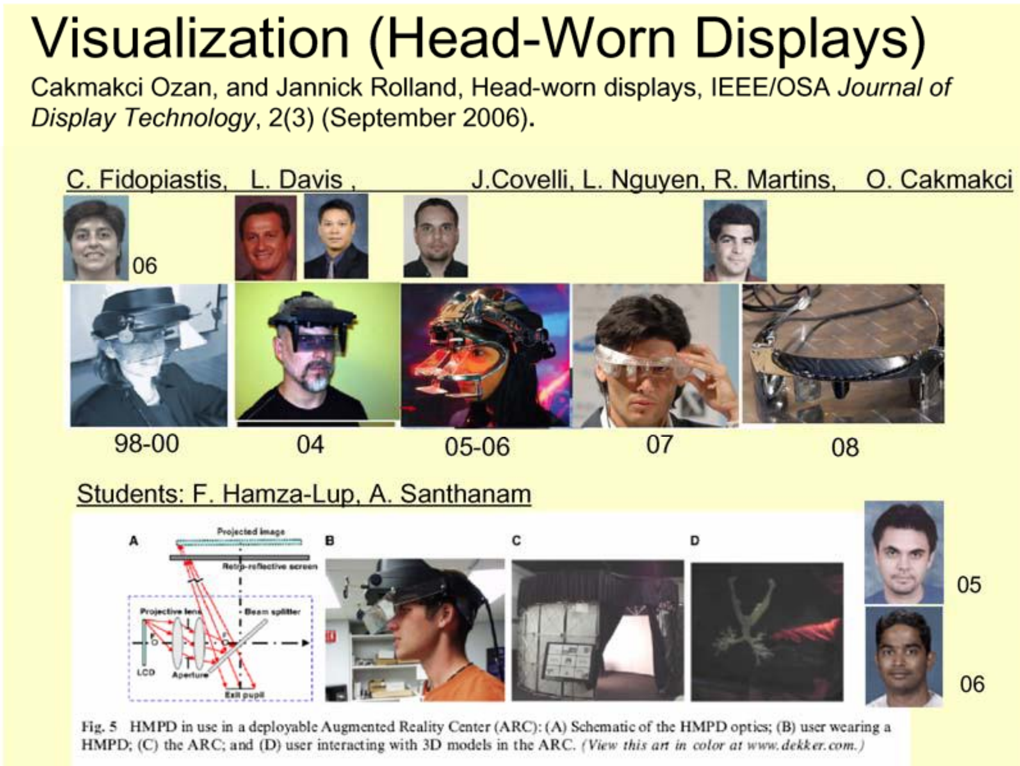
Development of a Kinematic Model of Joint Motion (Baillot, Rolland et al., 2000)

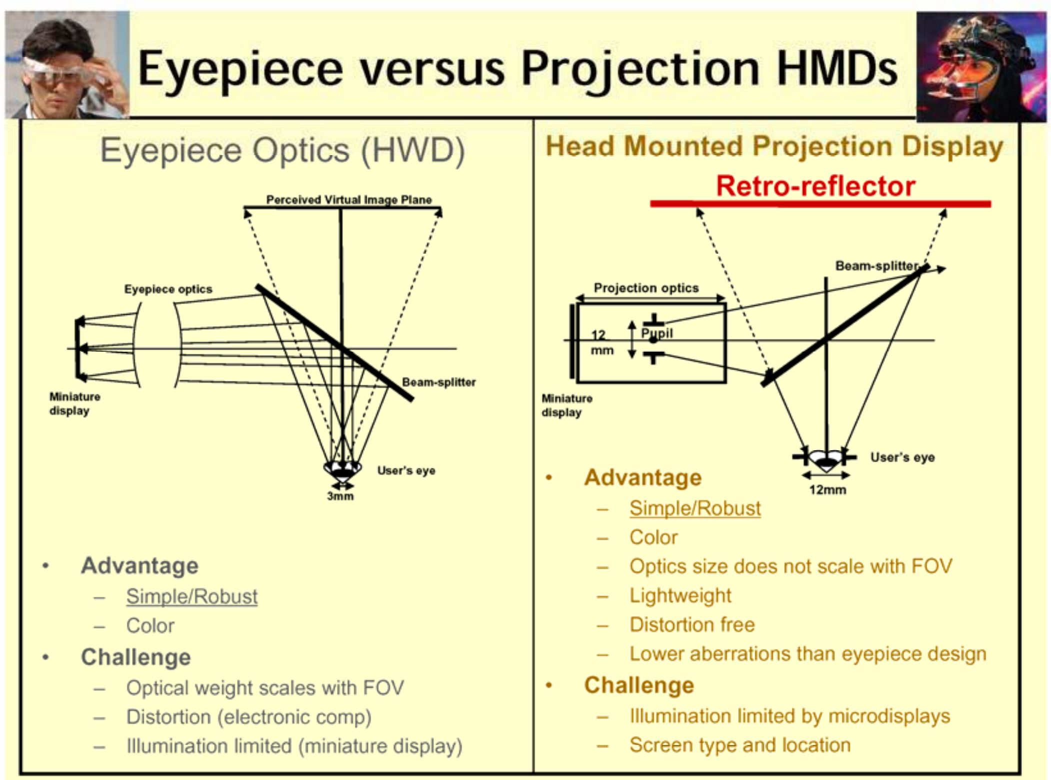
Early Feasibility Experiments

First results in dynamic optical superimposition on an optical bench system

Featured in Scientific American, April 2002

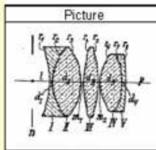
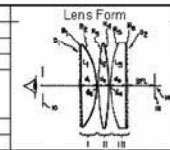
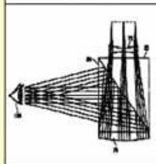
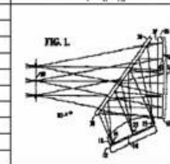
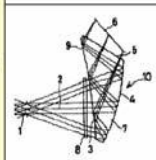
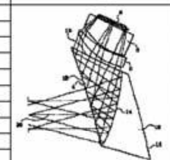
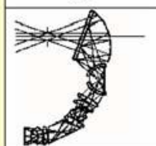
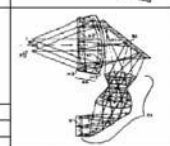
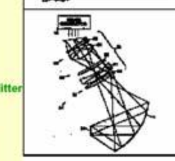
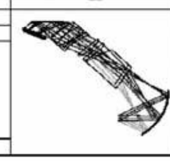
Baillot et al., Presence 2000; Argotti et al., Computers & Graphics 2002


Visualization (Head-Worn Displays)
Cakmakci Ozan, and Jannick Rolland, Head-worn displays, IEEE/OSA Journal of Display Technology, 2(3) (September 2006).
C. Fidopiastis, L. Davis , J.Covelli, L. Nguyen, R. Martins, O. Cakmakci
06
98-00
04
05-06
07
08
Students: F. Hamza-Lup, A. Santhanam
A
Projected image
Retro-reflective screen
Projective lens
Beam splitter
LCD
Aperture
Exit pupil
B
C
D
05
06
Fig. 5 HMPD in use in a deployable Augmented Reality Center (ARC): (A) Schematic of the HMPD optics; (B) user wearing a HMPD; (C) the ARC; and (D) user interacting with 3D models in the ARC. (View this art in color at www.dekker.com.)

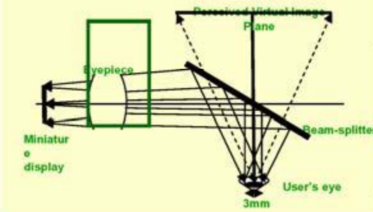

Eyepiece versus Projection HMDs
Eyepiece Optics (HWD)
Perceived Virtual Image Plane
Eyepiece optics
Miniature display
Beam-splitter
User's eye
3mm
• Advantage
– Simple/Robust
– Color
• Challenge
– Optical weight scales with FOV
– Distortion (electronic comp)
– Illumination limited (miniature display)
Head Mounted Projection Display
Retro-reflector
Projection optics
Beam-splitter
12 mm
Pupil
Miniature display
User's eye
12mm
• Advantage
– Simple/Robust
– Color
– Optics size does not scale with FOV
– Lightweight
– Distortion free
– Lower aberrations than eyepiece design
• Challenge
– Illumination limited by microdisplays
– Screen type and location

Review of "Large FOV" Eyepiece Optics Design

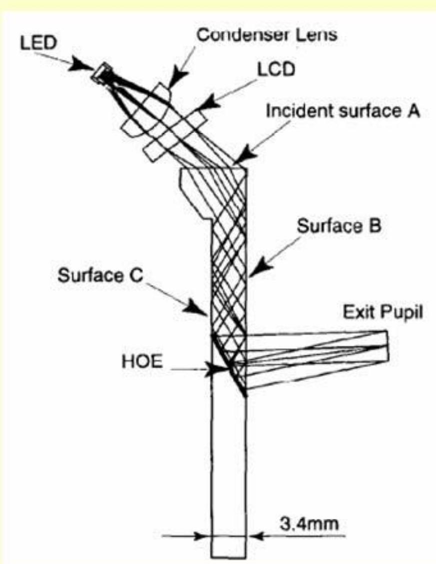
Rolland and Hua, 2005
Encyclopedia of Optical Engineering (Marcel Dekker)

Picture	Specification	Lens Form	Specification
	FOV 70 ELF 100 H. Erfle 1478704		FOV 70 EFL 100 Michael D. Missig 5446588
	FOV33 EFL 34 J. D. Robinson C. M. Schor P.H. Muller W.A. Yankee eyepiece 5696521		B.S. Fritz HMD using Mangin Mirror combiner 5838490
	FOV 40-60 EFL 100 Takayoshi Togino Eyepiece with DOE 6181475 5959780		FOV 40 15.2x12.3 MicroDisplay F#/1.7 J.G. Droessler Honeywell Inc Morristown, NJ 6147807
	FOV 50x60 J.G. Droessler D.J. Rotier Tilted Cat Ocular 1989		FOV 120 C. Antier Jean-Blaise Migozzi Holographic Binocular Helmet Visor 5124821
	FOV 50x60 color Helmet visor display B. Chen Off-axis Design 5526183		FOV 60 color 1.3" diagonal CRT J.P. Rolland Off-axis Design IODC94; OE 2000

Direct View ——→ See-through

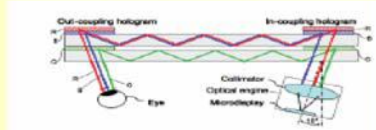


Related Work



Kasai. Int. Symp. Wearable Computers '00.

Resolution ~2 arcmins
FOV ~30 degrees
10 mm pupil [Lumus]



H. Mukawa et al. In Proc. Society of Information Display, 2008.

SONY

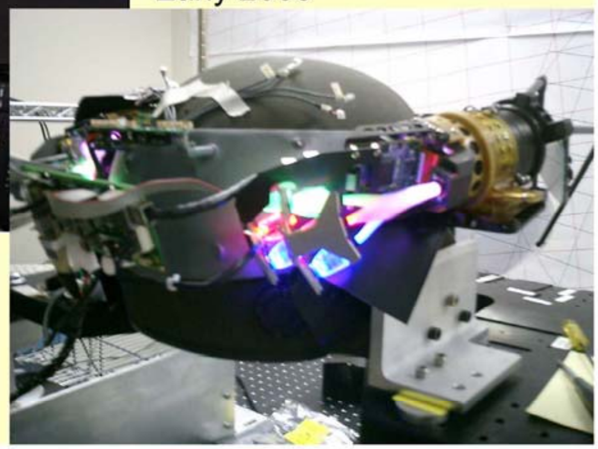
AHMD (Advanced HMD)
Ultrawide FOV, off-axis design

Courtesy of LINK/ZYGO and Optical Research Associates

Early 2000

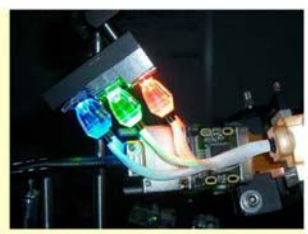
AHMD Specifications

Helmet compatibility	HGU-56/P, HGU-55/P all sizes
Center of gravity	Balanced
Eye relief	> 50 mm
Exit pupil	15 mm
Transmissivity	> 60%
Field-of-view	100° H x 50° V
Binocular overlap	30°
Resolution	1280 x 1024 per eye

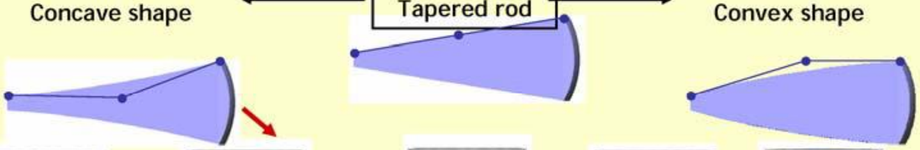


Spatial Uniformity Behavior with Freeform Bezier Shapes

Fournier et al., Appl. Opt. 47 (2008) & OL 33(11) (2008)



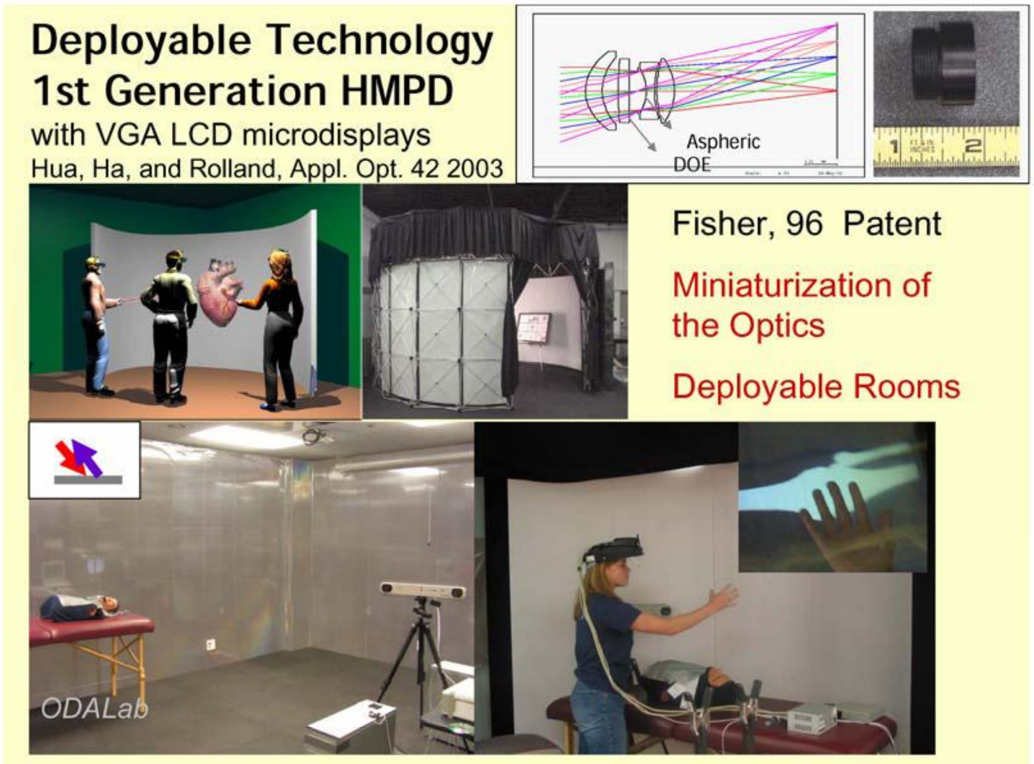
Towards Concave shape ← 30mm Tapered rod → Towards Convex shape

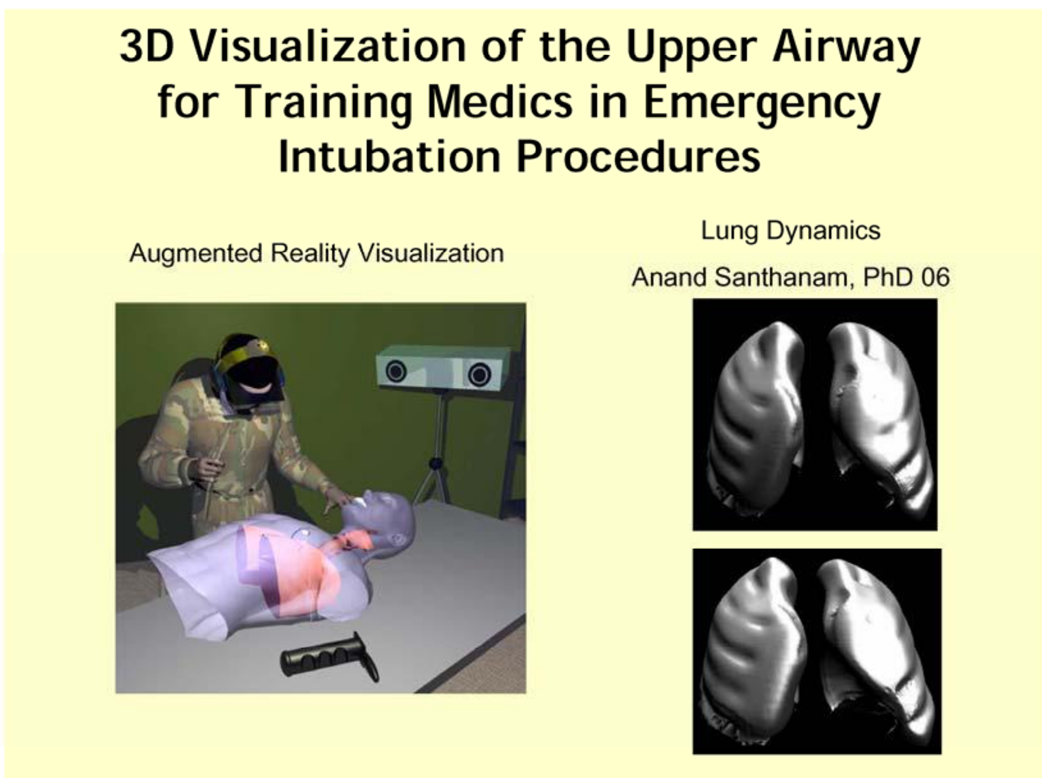


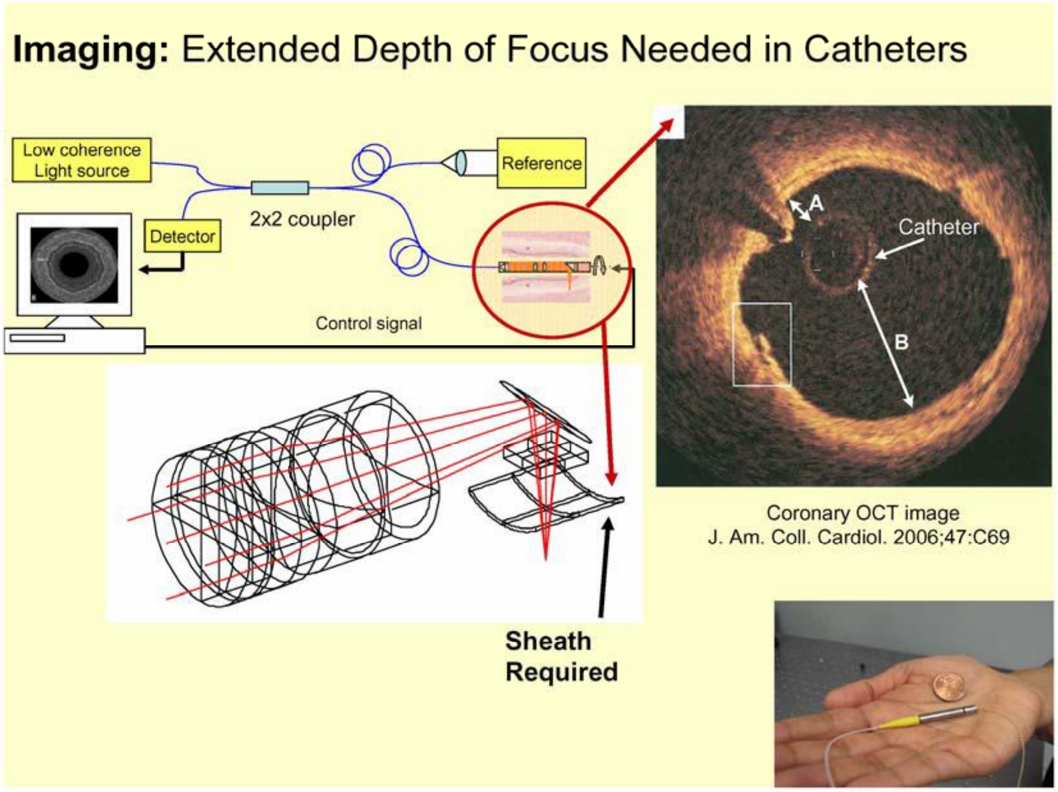
86.7% efficiency
2.5% non-uniform

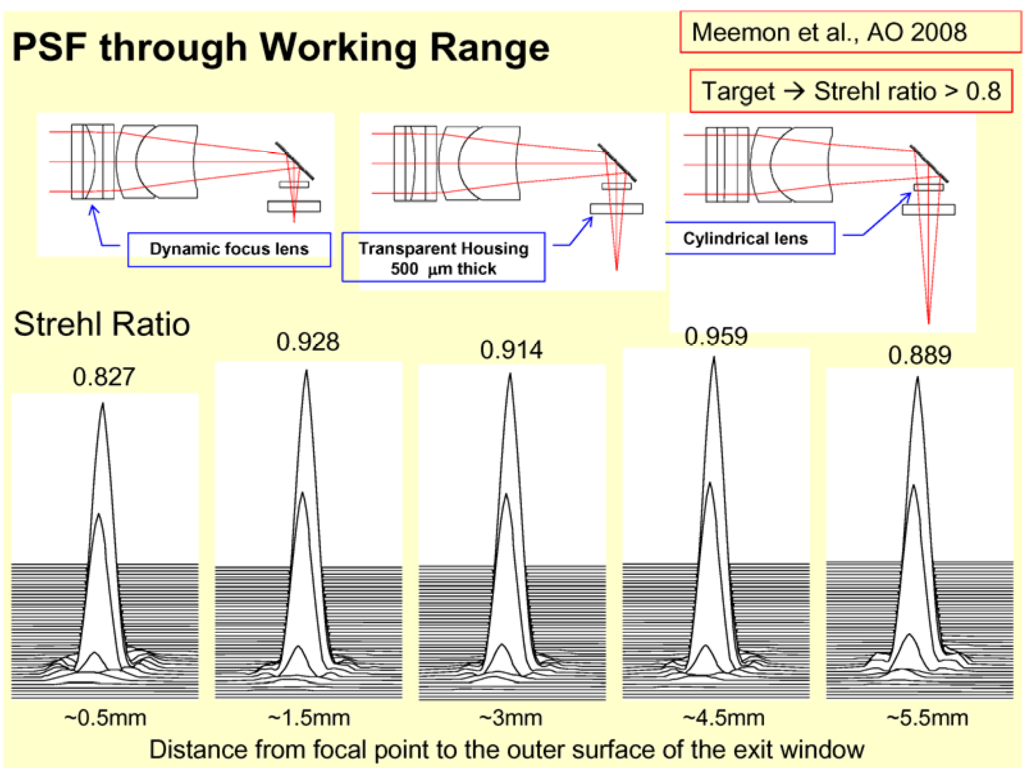
83.5% efficiency
8.1% non-uniform

Changing the concavity of the shape can improve uniformity without sacrificing efficiency

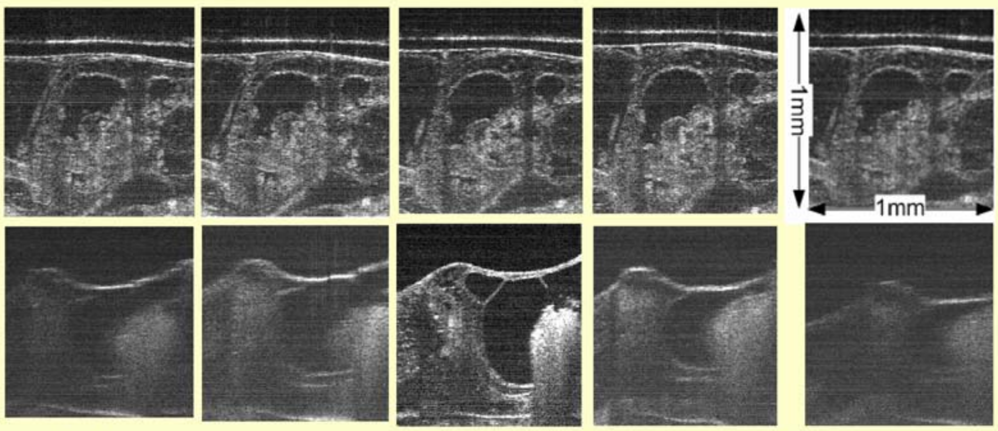

Deployable Technology
1st Generation HMPD
with VGA LCD microdisplays
Hua, Ha, and Rolland, Appl. Opt. 42 2003
Aspheric
DOE
Fisher, 96 Patent
Miniaturization of the Optics
Deployable Rooms
ODALab


3D Visualization of the Upper Airway for Training Medics in Emergency Intubation Procedures
Augmented Reality Visualization
Lung Dynamics
Anand Santhanam, PhD 06


Imaging: Extended Depth of Focus Needed in Catheters
Low coherence Light source
Reference
2x2 coupler
Detector
Control signal
A
Catheter
B
Coronary OCT image
J. Am. Coll. Cardiol. 2006;47:C69
Sheath Required


PSF through Working Range
Meemon et al., AO 2008
Target → Strehl ratio > 0.8
Dynamic focus lens
Transparent Housing 500 µm thick
Cylindrical lens
Strehl Ratio
0.827
0.928
0.914
0.959
0.889
~0.5mm
~1.5mm
~3mm
~4.5mm
~5.5mm
Distance from focal point to the outer surface of the exit window

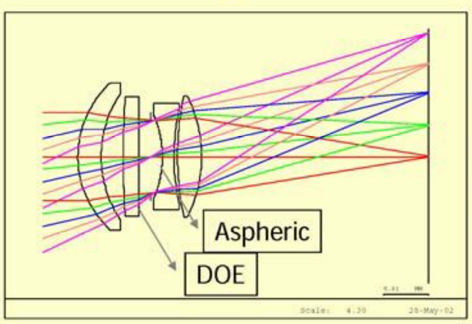
Bessel Beam vs. Conventional

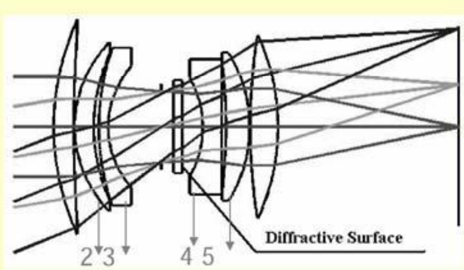


First Images of biological tissue acquired with a microlens axicon in a double pass OCT : Images of African frog (Xenopus Laevis) tadpole located at relative axial distances ***d*** from each medial position of its depth of focus.

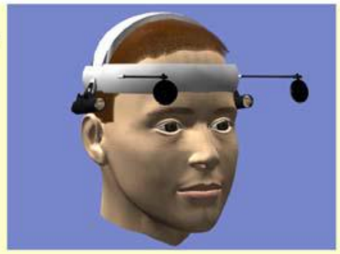
K. Lee and J. Rolland Optics Letters 33 (2008)

52 deg. Lens / 8g per eye





Teleportal Display
UCF/MSU



Reddy et al., CVPR'04

42° FOV HMPD
Lightweight 595 grams - 2nd Generation HMPD using 800x600 OLED

Optical Design done in the ODALab and

HMPD Optomechanical design done by Nvis Corporation

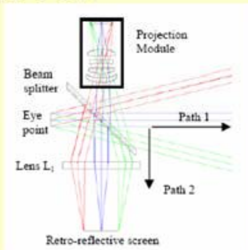
under SBIR program 2004-2005 with the US ARMY

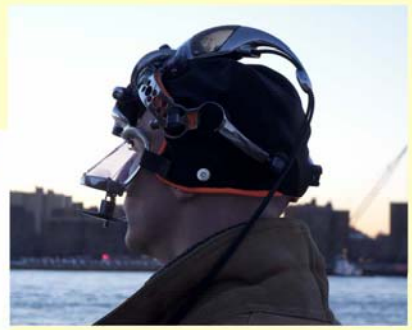
M-HMPD - Fabric-free, Mobile

Martins, Optics Express 15(22), 2007

See-through, Outdoor
42° FOV





A recent experiment with the MD Anderson Cancer Center Orlando to appear in JDT, Dec08

Comparison of the ARC system with the 2D display system

To appear in Special Issue of JDT, Dec 08

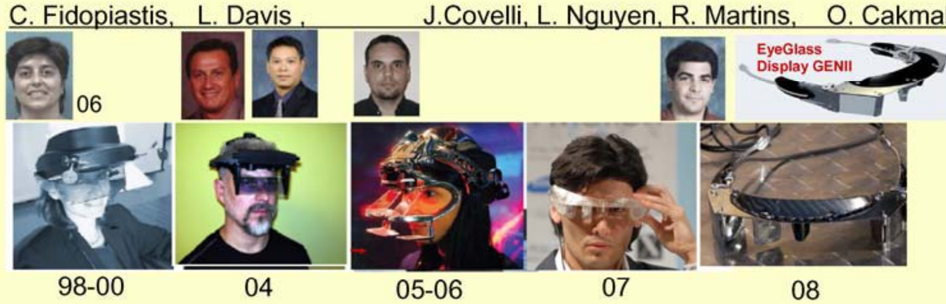
Subject	Average time (sec) Experiment 1		Average time (sec) Experiment 2		Average time (sec) Experiment 3	
	ARC	2D monitor	ARC	2D monitor	ARC	2D monitor
Expert 1	0	2.55	0.75	11.05	1.05	13.05
Expert 2	0	0.95	1.05	8.95	0.95	11.0
Expert 3	0.45	4.05	0.95	12.05	1.55	15.05
Expert 4	0	3.95	0.55	14.95	1.05	14.05
Expert 5	0.55	2.55	1.45	8.0	0.9	16.0
Expert 6	0	3.45	1.40	9.0	1.55	13.0
Average	**0.2**	**2.9**	**1.0**	**10.7**	**1.2**	**13.7**

The individual dose beams are delivered to a patient in 30-40 seconds, Thus, a 10 second delay in decision making is highly significant

Visualization (Head-Worn Displays)

Cakmakci Ozan, and Jannick Rolland, Head-worn displays, IEEE/OSA *Journal of Display Technology*, 2(3) (September 2006).

C. Fidopiastis, L. Davis , J.Covelli, L. Nguyen, R. Martins, O. Cakmakci



Students: F. Hamza-Lup, A. Santhanam

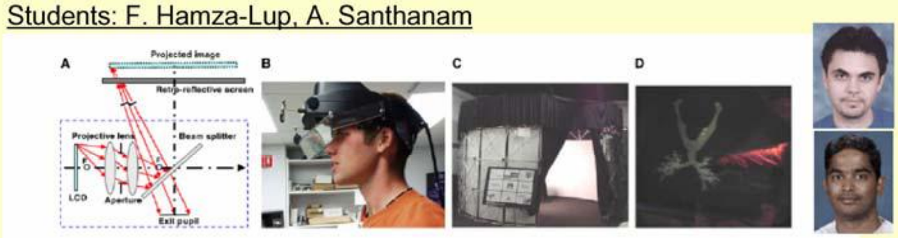


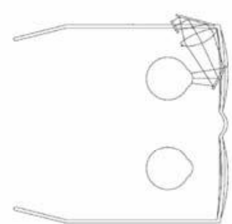
Fig. 5 HMPD in use in a deployable Augmented Reality Center (ARC): (A) Schematic of the HMPD optics; (B) user wearing a HMPD; (C) the ARC; and (D) user interacting with 3D models in the ARC. *(View this art in color at www.dekker.com.)*

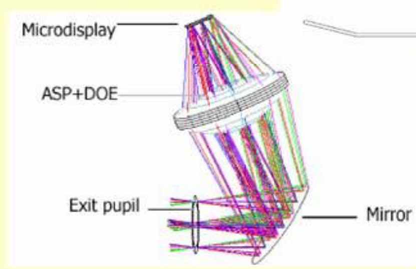
FREE FORM OPTICS

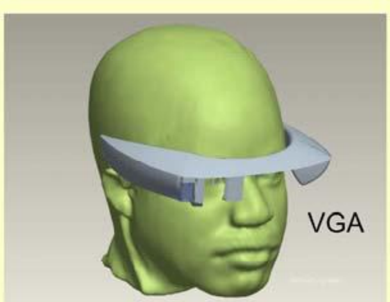
Eyeglass Display

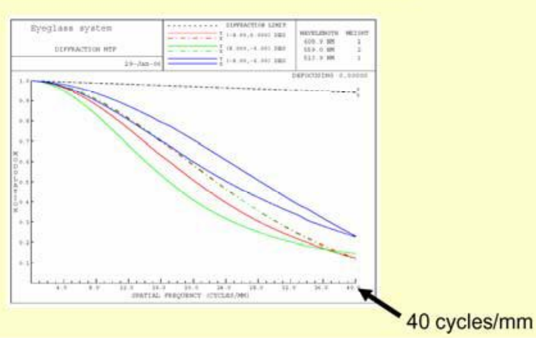
Ozan Cakmakci, *Kidger Scholarship 05*

Cakmakci & Rolland, *Journal of Display Technology*, (2006).



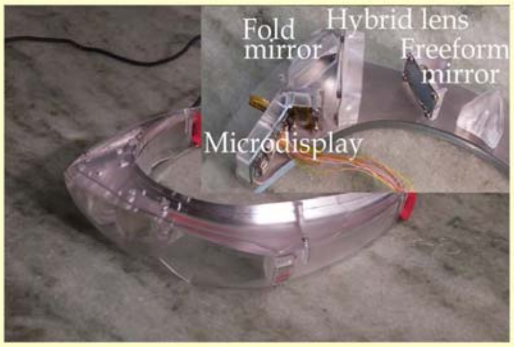






Dual-element Solution

Cakmakci & Rolland, OL 32(11), 2007



Field of view: up to 25 FOV diagonal
Resolution: ~1.5 arcminutes
Exit pupil size: up to 12mm
Eye clearance: >15 mm
Distortion: <4%
Wavelengths: 450-650nm

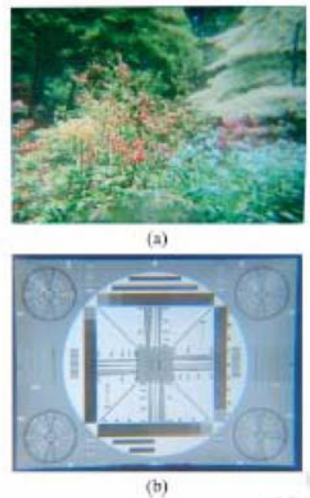
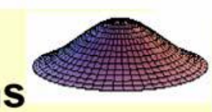
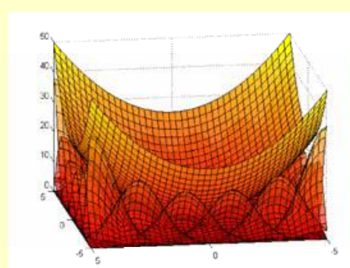


Fig. 2. (Color online) Photograph through the fabricated dual-element system of (a) a color target and (b) a black and white target.

We Propose to Design Freeform Optical Surfaces whose Representations use Local Basis Functions (as Opposed to Global Polynomials)



- An optical surface can be represented as a sum of basis functions



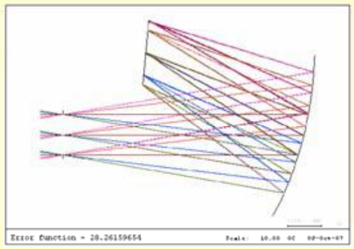
$$z(x,y) = \sum \phi_i(x,y) w_i$$

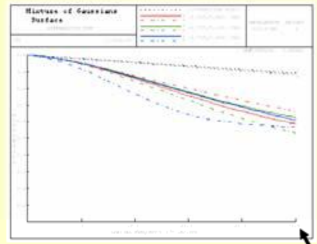
- In matrix form

$$z = \Phi w$$

- To be invertible, Φ must be positive definite. equivalent to having positive eigenvalues.

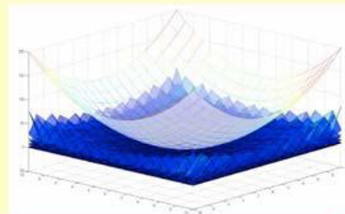
Results





Surface type	Average MTF	Max. Distortion
Anamorphic asphere	26.5%	3.8%
X-Y polynomial	43.6%	2.65%
Zernike polynomial	42%	3.74%
Lin. Comb. of Gaussians	**60.5%**	**3.6%**

40 cycles/mm

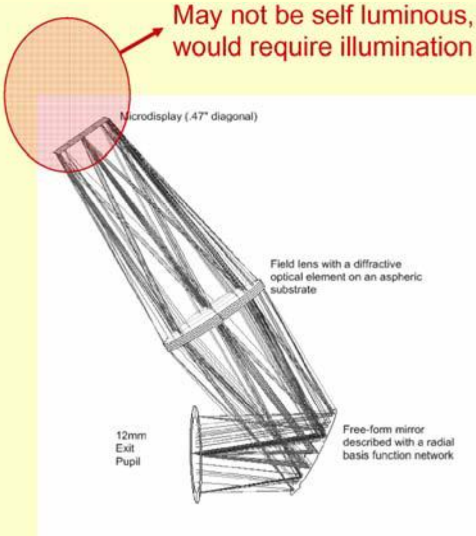


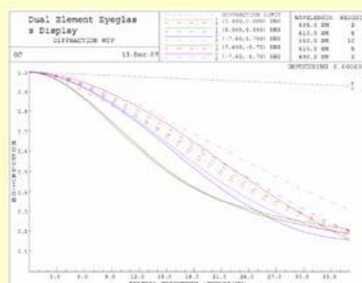
Cakmakci et al., Optics Express 16(3) (2008)

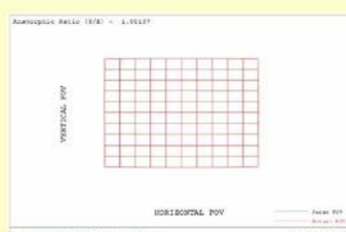
Revisiting the Dual-Element Design: Pupil Size Expansion

Cakmakci et al. OL (April 2008)

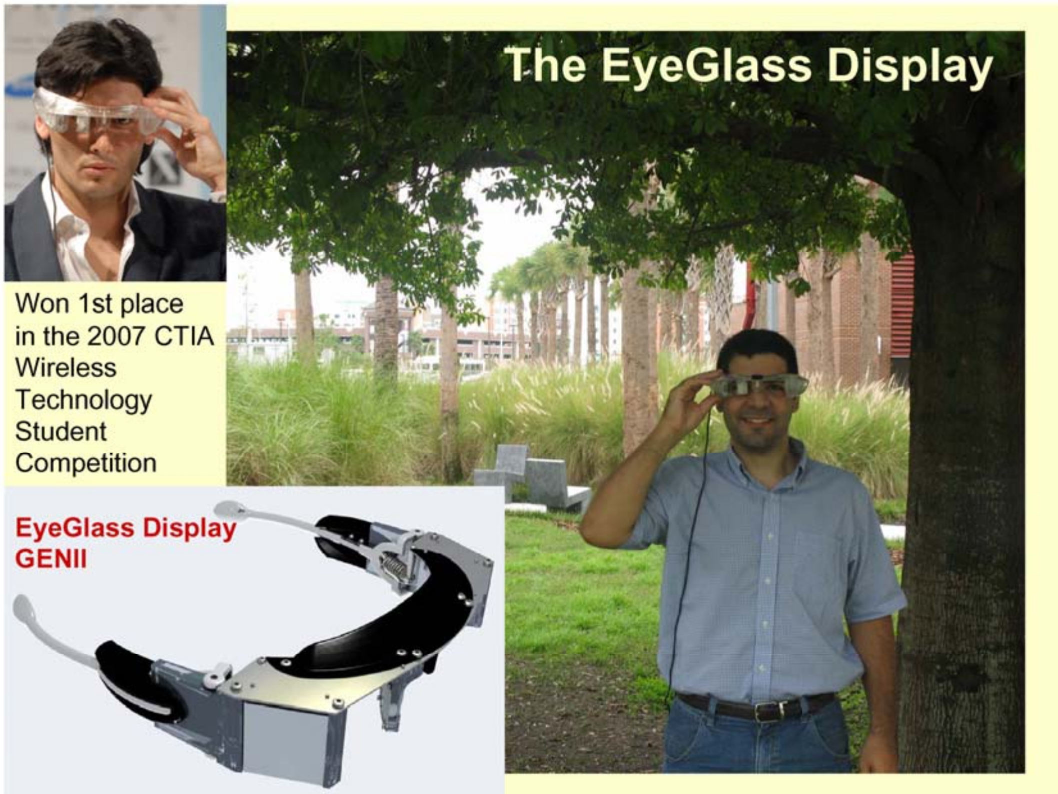
May not be self luminous, thus would require illumination







Using a 16x16 set of basis functions.



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- NASA
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