Arrayoptik für ultraflache Datensichtbrillen

Peter Schreiber,
Fraunhofer Institut für Angewandte Optik und Feinmechanik IOF, Jena

1. Introduction

2. Conventional near-to-eye (N2E) projection optics
   - first order description
   - problems

3. Arrayed microprojectors for front projection
   - principle of operation
   - manufacturing
   - basic properties

4. Arrayed microprojectors for N2E projection
   - principle of operation
   - lab demo

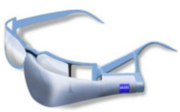
5. Conclusion and Outlook

1. Introduction

Data goggles

Google glasses

Entertainment
Virtual reality

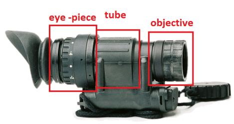


Zeiss

View finder

Canon

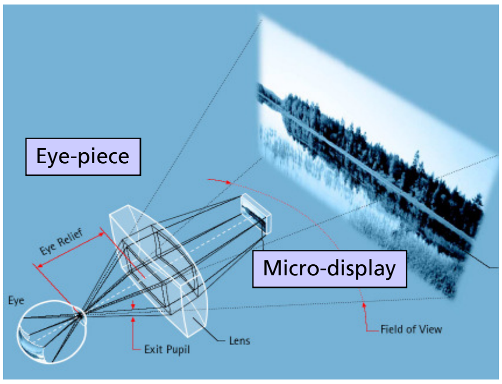
Night vision



Thales

<u>Design goals</u>
- small (slim)
- light-weight
- large field-of-view (FOV)
- large eye-motion box (EMB)
- large resolution (pixel number)
- high brightness
- see-through or segmented FOV

2. Conventional N2E projection optics: Basic building blocks

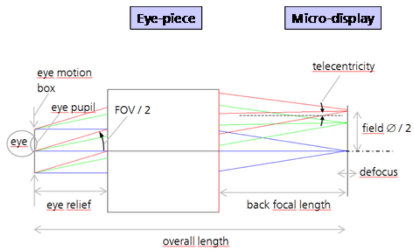


Option: "see-through"
(requires optical combiner)

2. Conventional N2E projection optics: Basic building blocks

Eye-piece:
- focal width f
- rel. aperture f/# = f/D

Micro-imager:
- field diameter



Design goals		Requirements
large FOV ≈ field dia. / f	→	large imager, medium focal width (>imager dia.)
small overall length ≈ f	→	small focal width
large EMB ≈ f / f/#	→	large focal width, small f/# (complex, large optics)

Work-around: folded free-form optics, pupil expander

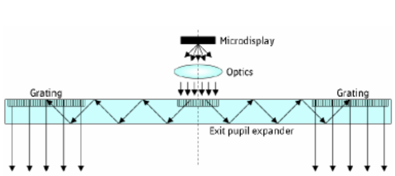
2. Conventional N2E projection optics: Folded optics examples

	Eye-Trek FMD 220	Z800 3dvisor	*i* Visor	ProView SL40	Our Design
Module view					
Full diagonal FOV (°)	37	39.5	42	40	53.5
Eye relief (mm)	23	27	22	30	18.25
Exit pupil diameter (mm)	4	4	3	5	8
Effective focal length (mm)	21	22	26.7	20.6	15
Diagonal image size (in.)	0.55	0.61	0.81 [a]	0.59	0.61
f/#	5.25	5.5	8.9	4.1	1.875

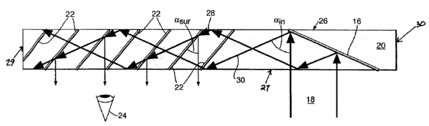
Comparison of actual free-form prisms (Cheng et al., Appl. Opt. 48, 2009).

Free-form prisms:
- Very precise surface profiles required
- Difficult to manufacture and assemble

2. Conventional N2E projection optics: Pupil expander examples



exit-pupil expander using planar waveguides (Järvenpää et al., "Compact near-to-eye display with integrated gaze tracker," Proc. SPIE Vol. 7001, 2008). Patent applications BAE, UK and Nokia, Fi.

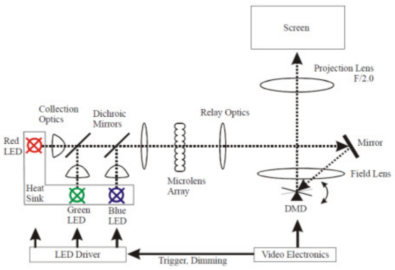


exit-pupil expander using parallel array of beam-splitters (US 7672055 B2 by LUMUS Ltd, March 2010)

Manufacturing
- Problems: Diffractive gratings efficiency, ghosting
- Very good parallelness of the image guide required

3. Arrayed microprojectors for front projection: Motivation

Array front projection: First motivation "Bright but thin" LED projectors



E. Geissler, SPIE 6196(2006)619601

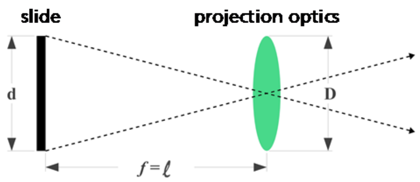
Flux scaling of LED illuminated projection displays

- Projected flux is etendue-limited
- etendue determined by area of microimager and f/# (acceptance angle) of projection lens
- Flux scaling results in increased projector size in 3D

3. Arrayed microprojectors for front projection: Principle

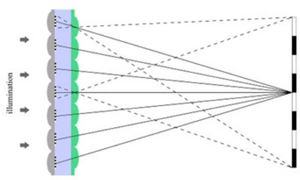
Single aperture slide projector

$$\Phi \sim \frac{d^2}{(f\#)^2} \sim \frac{D^2}{(f\#)^2} \sim \frac{l^2}{(f\#)^4}$$



Arrayed microprojector

1. Miniaturize the projector as much as possible
   (resolution limited: from diffraction or aberration)
   Option: add field lenses to achieve Köhler illumination
2. Increase number of „projectorlets" until required flux is reached
3. Superpose images on screen

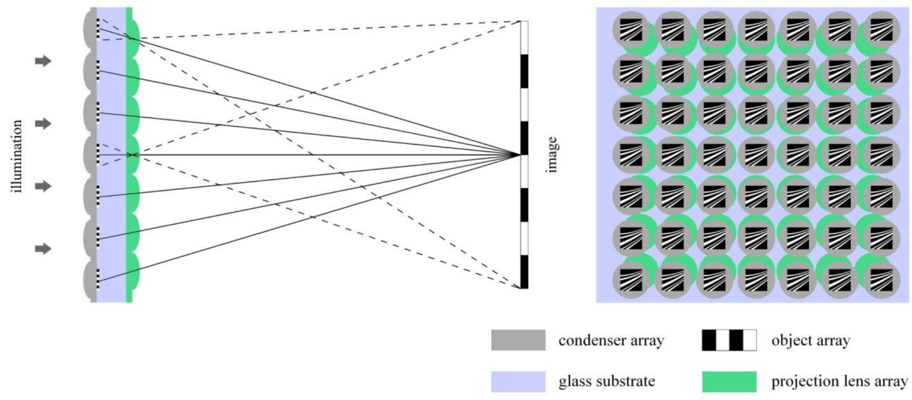


>> **Flux scaling by increasing projector area (only two dimensions !)**

>> get homogenization of illumination for free

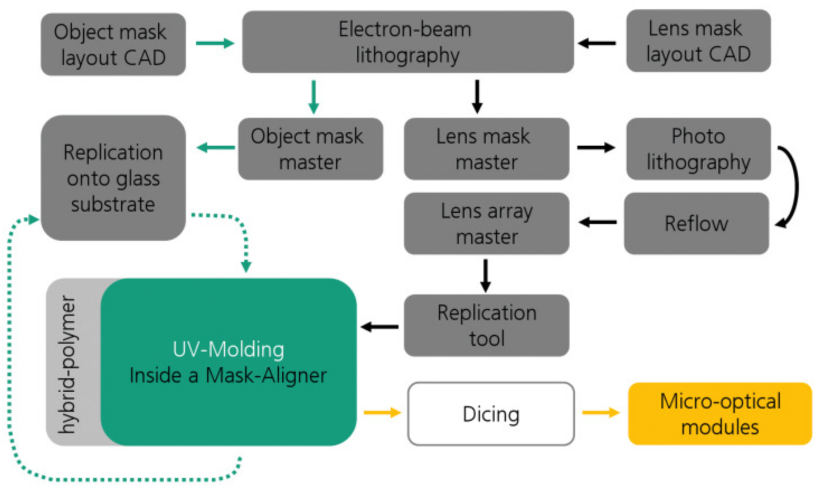
3. Arrayed microprojectors for front projection: Principle

- optics setup analogous to focused fly´s eye condenser + buried slide-array



M. Sieler et al. "Ultraslim fixed pattern projectors with inherent homogenization of illumination", Appl. Opt. 51(2012)64

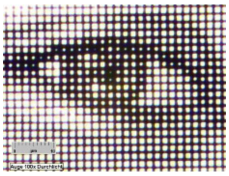
3. Arrayed microprojectors for front projection: Manufacturing

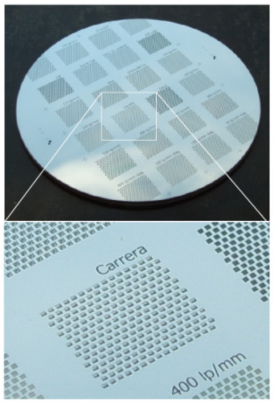


3. Arrayed microprojectors for front projection: Manufacturing

Microslide array

- **mastering:** by e-beam lithography
- **replication:** contact copy (mask aligner)
- pixelpitch 2µm
- greyscale images with (subpixel 125nm)

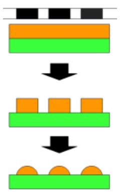




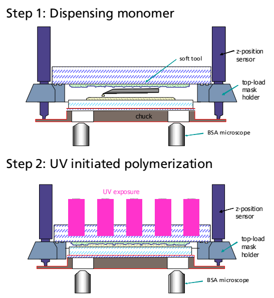
3. Arrayed microprojectors for front projection: Manufacturing

Microlens array

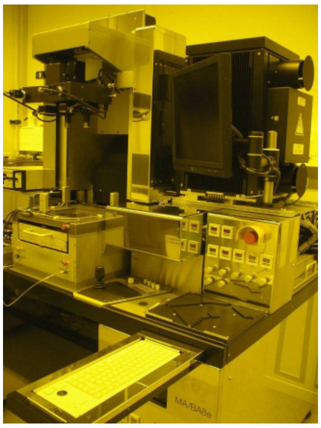
- **mastering:** reflow of lith. structured resist
- **replication:** UV-molding into polymer-on-glass
- lens pitch 0.5…1.5mm (typical)
- lens sag 50…200µm (typical)



Reflow process



Replication

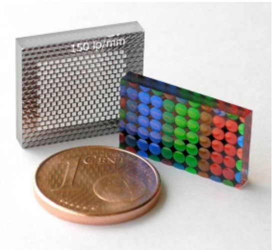


SUSS MA8 mask aligner

3. Arrayed microprojectors for front projection: Manufacturing

Complete microprojector (examples):

- 12x15x3mm³
- 15x15 projectors
- 260x260 pixels



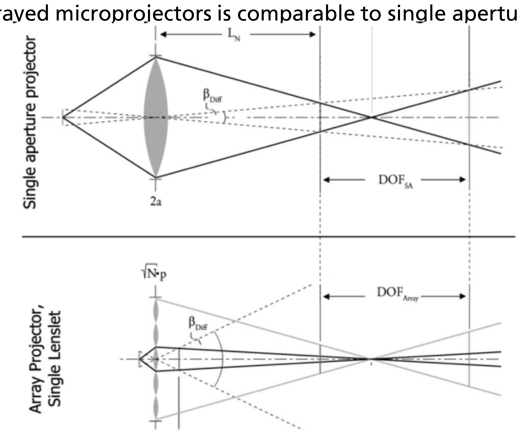
Samples with and without buried color filters

Test setup with collimated white LED for greyscale projection with QVGA resolution, projected flux 35lm

3. Arrayed microprojectors for front projection: Properties

Depth of focus

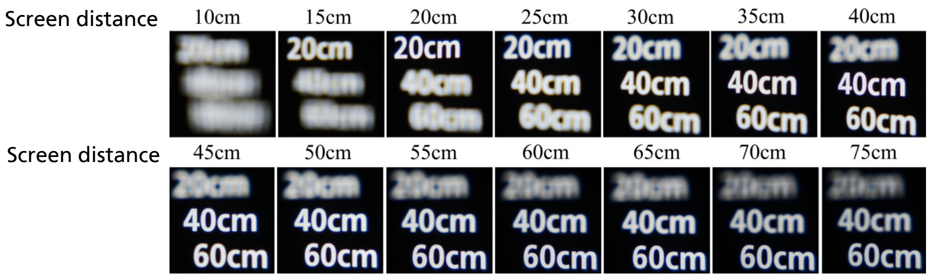
- (Very) large DoF of individual channels because of small lenslet aperture
- But: DoF of arrayed microprojectors is comparable to single aperture projector



3. Arrayed microprojectors for front projection: Properties

Depth of focus

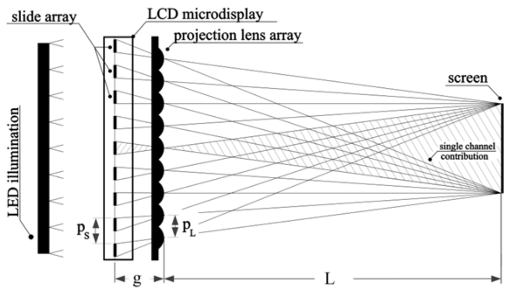
- Option: Image content varying with projection distance



3. Arrayed microprojectors for front projection: Video array front projector

LCD array projector

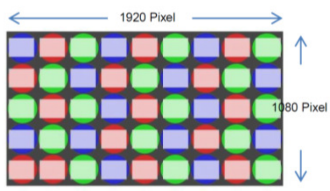
- Extention to projection of dynamic image content seems straight-forward:
  - Replace slide array by micro-imager (i.e. LCD)
  - Image pre-processing to form subimages
- Problems:
  - Too large imager pixels (5…10µm) >> less projected pixels per channel
  - multiple identical subimages >> less projected pixels



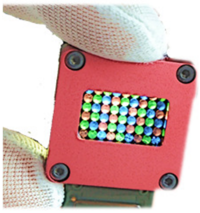
3. Arrayed microprojectors for front projection: Video array front projector

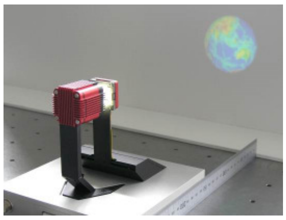
LCD array projector

- only 8.5mm thick
- RGB color channel-wise
- projected flux 12lm
  (RGB filters, no pol.-recycling…)
- 200x150 pixels, dynamic RGB-content



M. Sieler, P. Schreiber, A. Bräuer, „Microlens array based LCD projection display with software-only focal distance control", Proc. of SPIE Vol. 8643 86430B-4



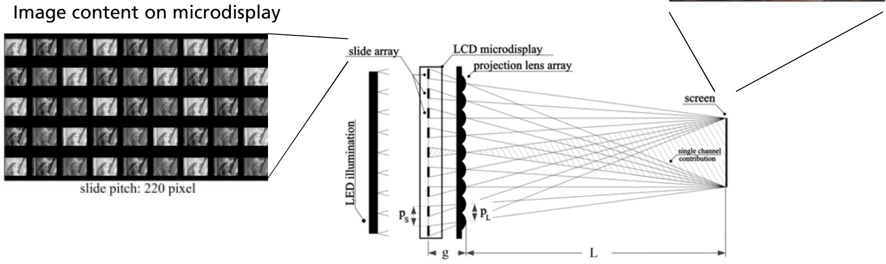


3. Arrayed microprojectors for front projection: Video array front projector

LCD array projector

- Image pre-processing defines projection distance
- Software-only focusing without mechanically moving parts !

Image content on microdisplay



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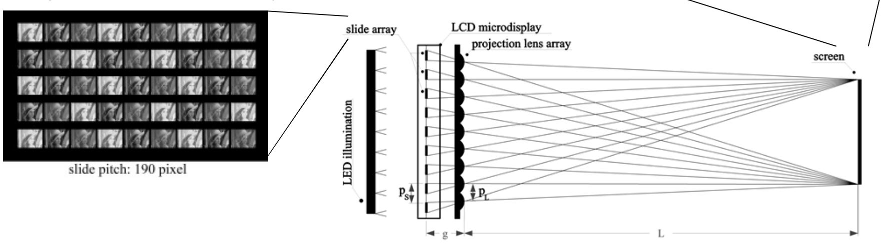

3. Arrayed microprojectors for front projection: Video array front projector

LCD array projector

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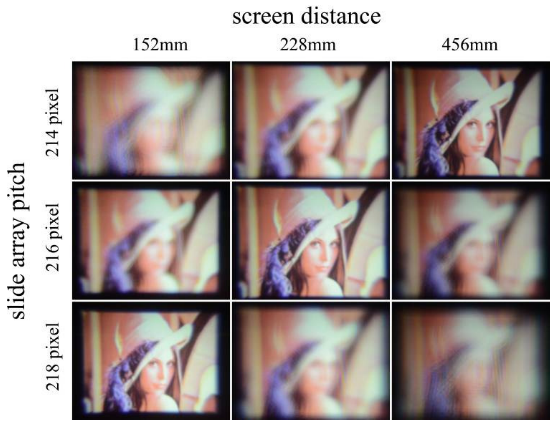
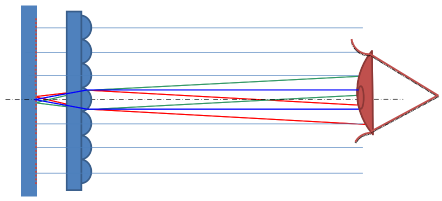


4. Arrayed microprojectors for N2E projection: Principle

Basic idea: Use a multitude of microprojectors to form a virtual image for N2E

Use array projector focused to infinity "as is":



Properties:

- \+ Extremely slim !
- \+ Large EMB = Imager diameter !
- – Small FOV = FOV of a single array channel (typ. 10…15°)
- – Small resolution i.e. small pixel number (<QVGA even for HD micro imager !)
- – Visible artifacts of array structure

4. Arrayed microprojectors for N2E projection: Principle

Advanced system with partially overlapping local FOV (Pat. pending):

Optics scheme

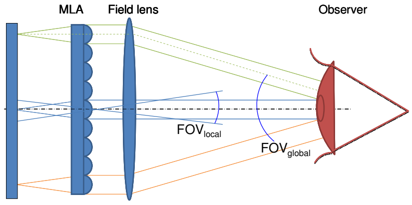
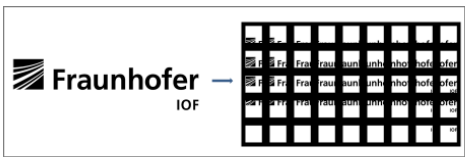


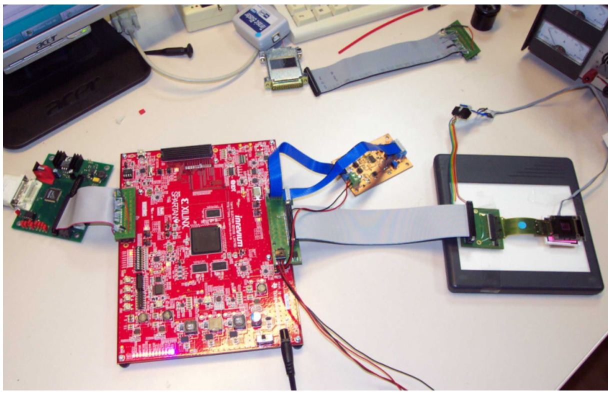
Image preprocessing



Properties:

- \+ very slim !
- \+ medium EMB (= few array pitches – depending on local FOV overlap)
- \+ medium FOV = global FOV + local FOV (20…40°)
- \+ eye-clearance controllable by field lens focal width
- • sufficient resolution (VGA…SVGA)
- • suppression of visibility of array structure artifacts

4. Arrayed microprojectors for N2E projection: Lab demo



RGB modified backlight

2kx1k LCD, 8.5µm pixel

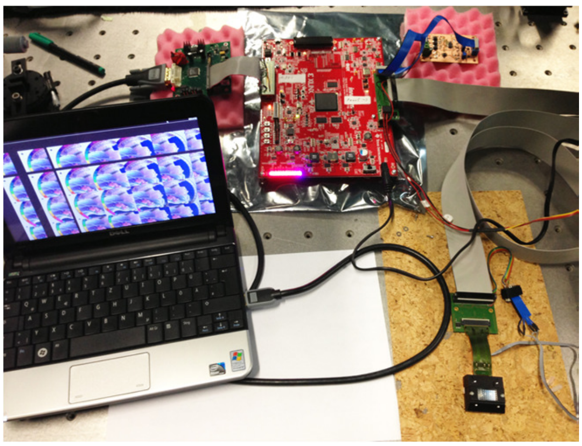
µ-lens array

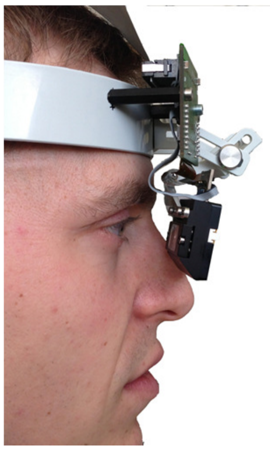
Fresnel field lens

Housing

Driving electronics (sequential color)

4. Arrayed microprojectors for N2E projection: Lab demo





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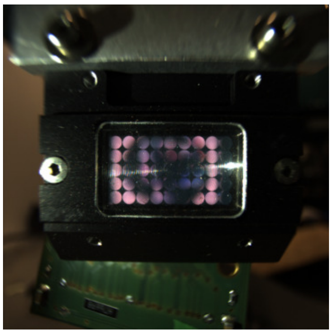


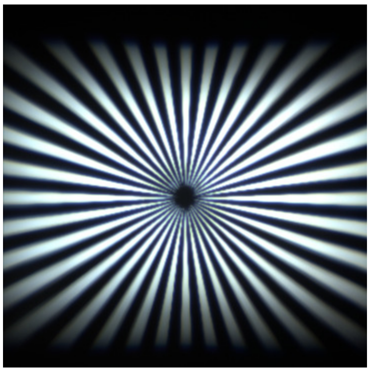
Photograph from large distance

Photograph of projected RGB image
(Difficulties with image captues)

5. Conclusion and outlook

<u>Status:</u>
- Near-to-eye array-projector lab demo realized
- RGB system with resolution comparable ca. VGA
- 2kx1k LCD micro-imager with 8.5µm pitch
- ca. 35° FOV
- Overall system thickness <10mm
- Electronic control of focusing

<u>Next steps:</u>
- Resolution enhancement up to SVGA using µ-imager with smaller (and more) pixels (4kx2k @ 4µm pitch)
- Combination with image guides for see-through operation: perfect fit of geometry !
- Combination with nested camera for eye-tracking: precise positioning of eye w.r.t. to optics (helpful for cross-talk suppression)

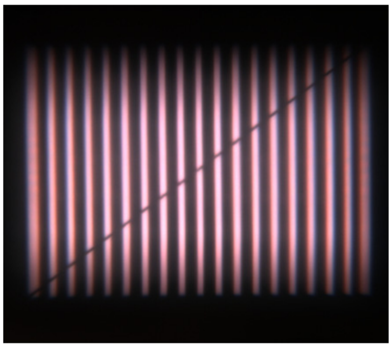


5. Conclusion and outlook

Advantages:
- extremely slim form factor
- electronic control of projection distance
- electronic correction of displacement of glasses
- good chances for IP protection
- well established micro-optics technology (polymer-on-glass lens arrays + Fresnel optics)
- tolerance w.r.t. pixel failure

Prospects:
- stereoscopy + accomodation control for 3D
- multiple projection distances within one virtual picture
- electronic low vision correction

Challenges:
- Hi Res microimagers (>4kx2k pixels, <4µm pitch) LCD, LCoS or OLED required
- Ghost image (cross-talk) suppression (collimated backlight, baffles…)



Acknowledgement

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