# Multi-user autostereoscopic display based on direction-controlled illumination using a slanted cylindrical lens array

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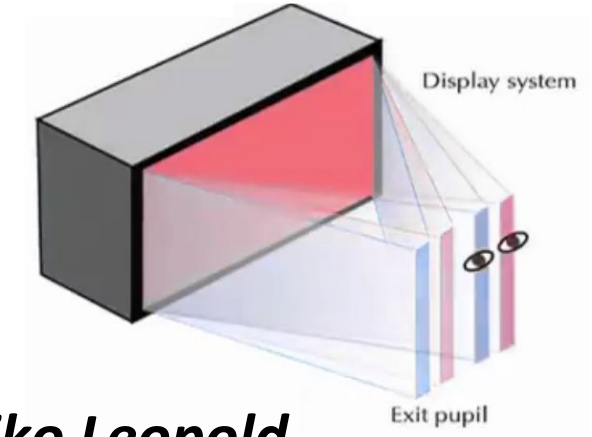
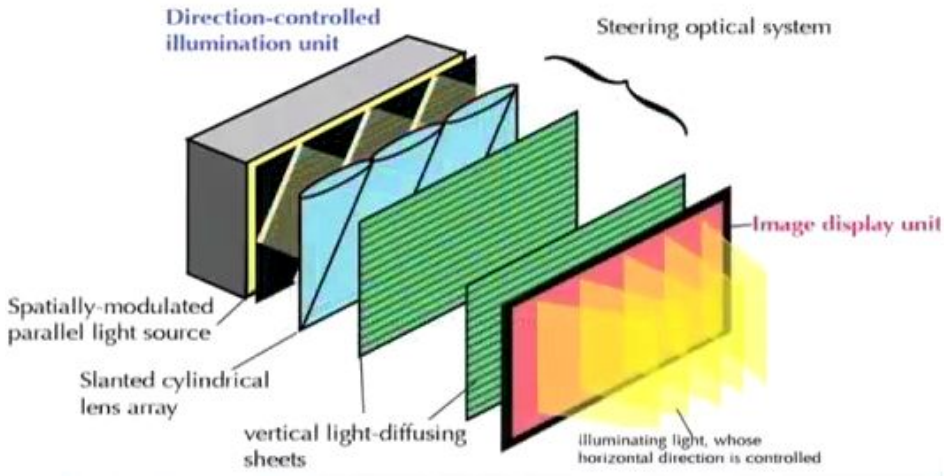
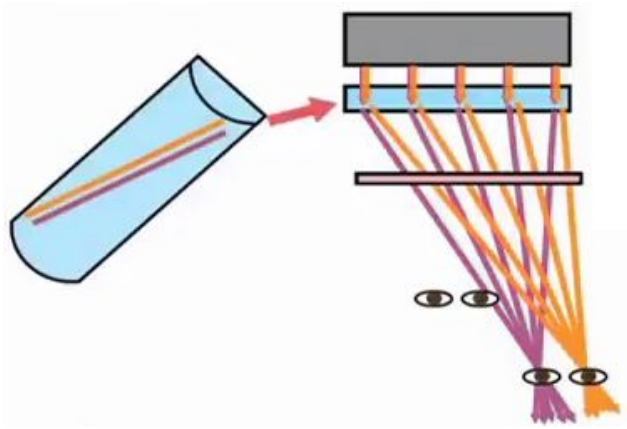
**Daisuke Miyazaki, Yui Hashimoto, Kenta Okoda**
Osaka City University (Japan)
**Takahiro Toyota, Tetsuro Okuyama, Toshikazu Ohtsuki, Akio Nishimura, Hiroyuki Yoshida**
Panasonic Corporation (Japan)



# Motivation: Multi-user Auto-stereoscopic display

What we want

- **Auto-stereoscopic:** No need to put on 3D glasses
- **Multi-user:** Possible to experience the 3D effect from multiple angles

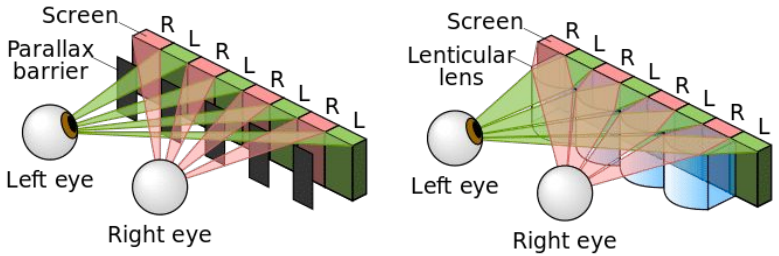
http://www.visioburst.com/wp-content/uploads/2011/01/ecran52.jpg

https://i.ytimg.com/vi/yExNdYofjbs/maxresdefault.jpg

# 1. Related Work on Auto-Stereo Displays

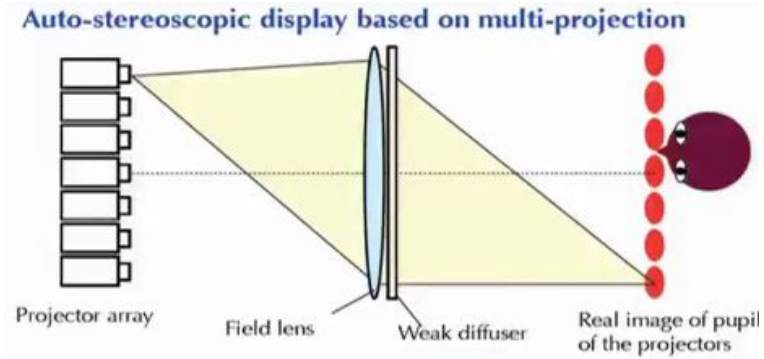
How to show images of different parallax at different exit pupils?

- **Parallax barriers or lenticular lens array, e.g. [2005 Dodgson]**
  - + commercially available
  - – degradation of image resolution by optical elems.
  - – restriction of viewing position




http://www.rissah.com.au/wp-content/uploads/2017/10/glassless-3D-lenticular-lenses.jpg.png

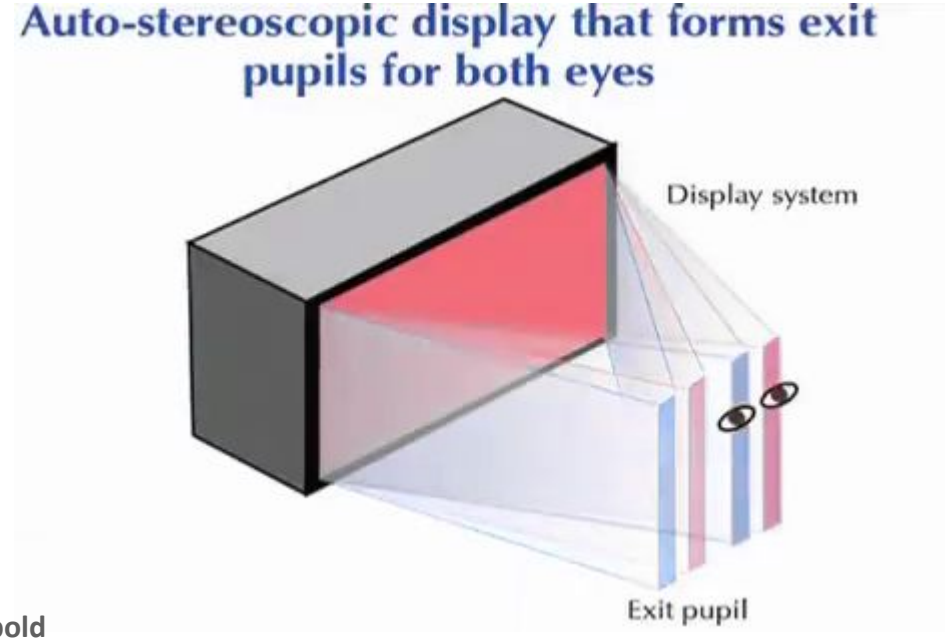
- **Multi-projector method, e.g. [2011 Iwasawa et al.]**
  - + large viewing region
  - + no degradation of image resolution
  - – requires large volume to fit many projectors
  - – high cost

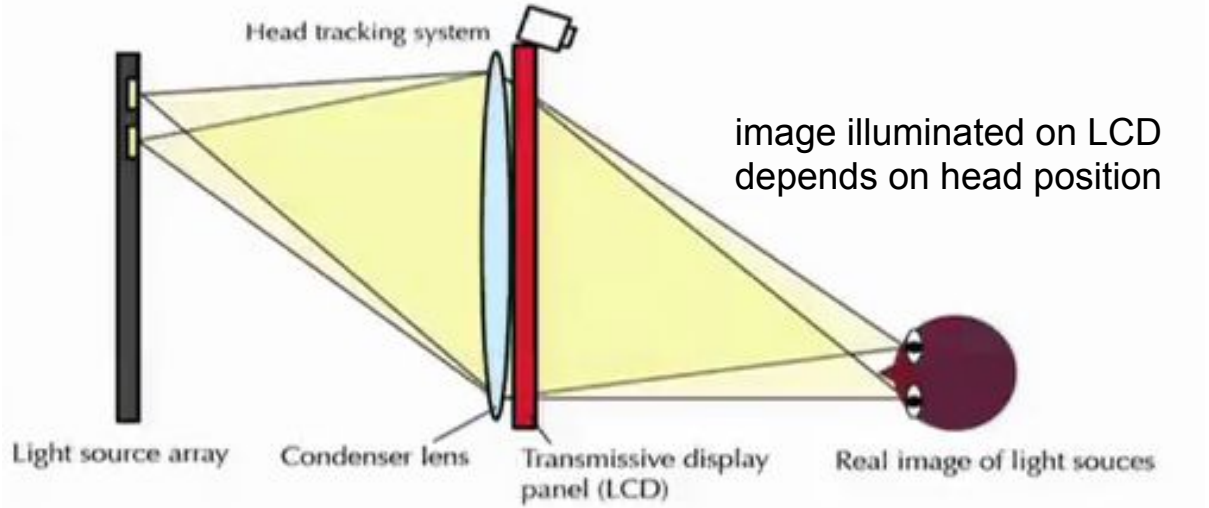



Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# 1. Related Work on Auto-Stereo Displays (2)

- **Auto-stereo display using spatially distributed light sources and field lens**
  - \+ larger viewing angle than parallax barrier or lenticular array
  - \+ no degradation of image resolution
  - \+ lower cost and more compact than multi-projector method
  - – restriction of exit pupils to certain distance from display
  - – requires head tracking to form exit pupils at both eyes



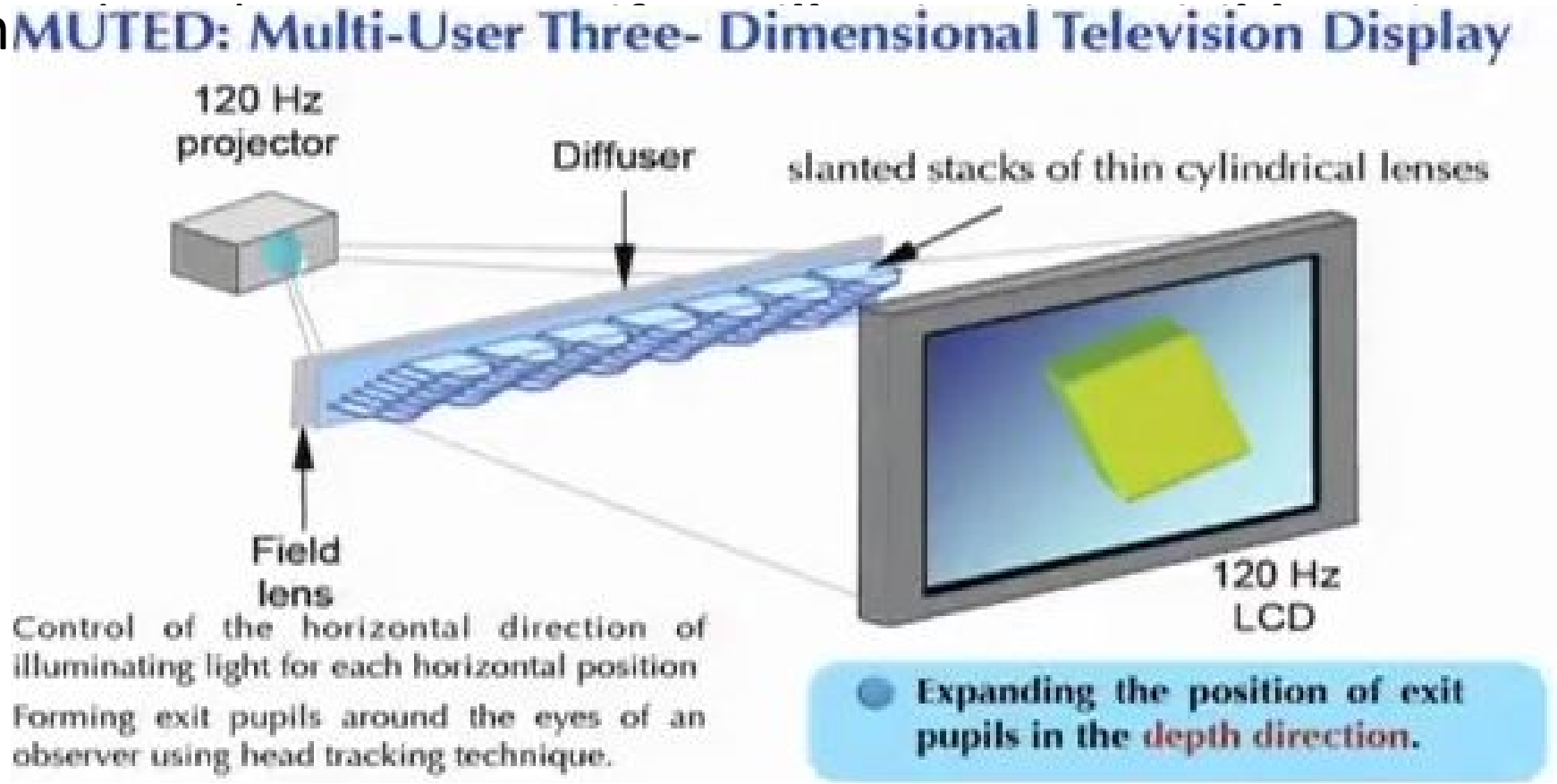

both images: Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# Multi-user Auto-stereo display (MUTED) [2010 Surman et al]

+ viewing angle + no degradation of resolution + lower cost

+ **greater depth range of exit pupils + multi-user (exit pupils at multiple views)**

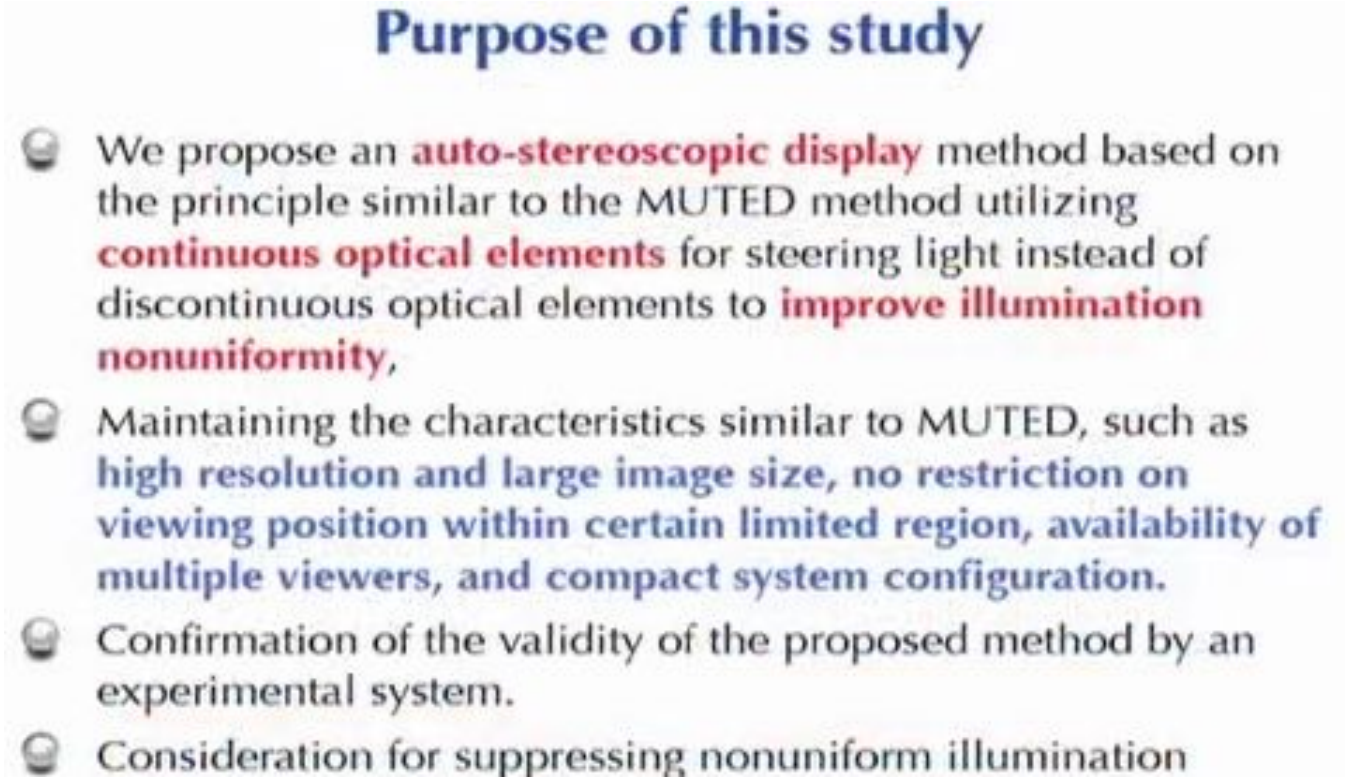
– requires h




Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# Multi-user Auto-stereo display [2014 Miyazaki et al.]

**improvement** of [2010 Surman et al.] MUTED method:
**improves illumination uniformity** by replacing discontinuous optical elements for steering light (slanted stacks of thin cylindrical lenses) with continuous ones (long cylindrical lenses).

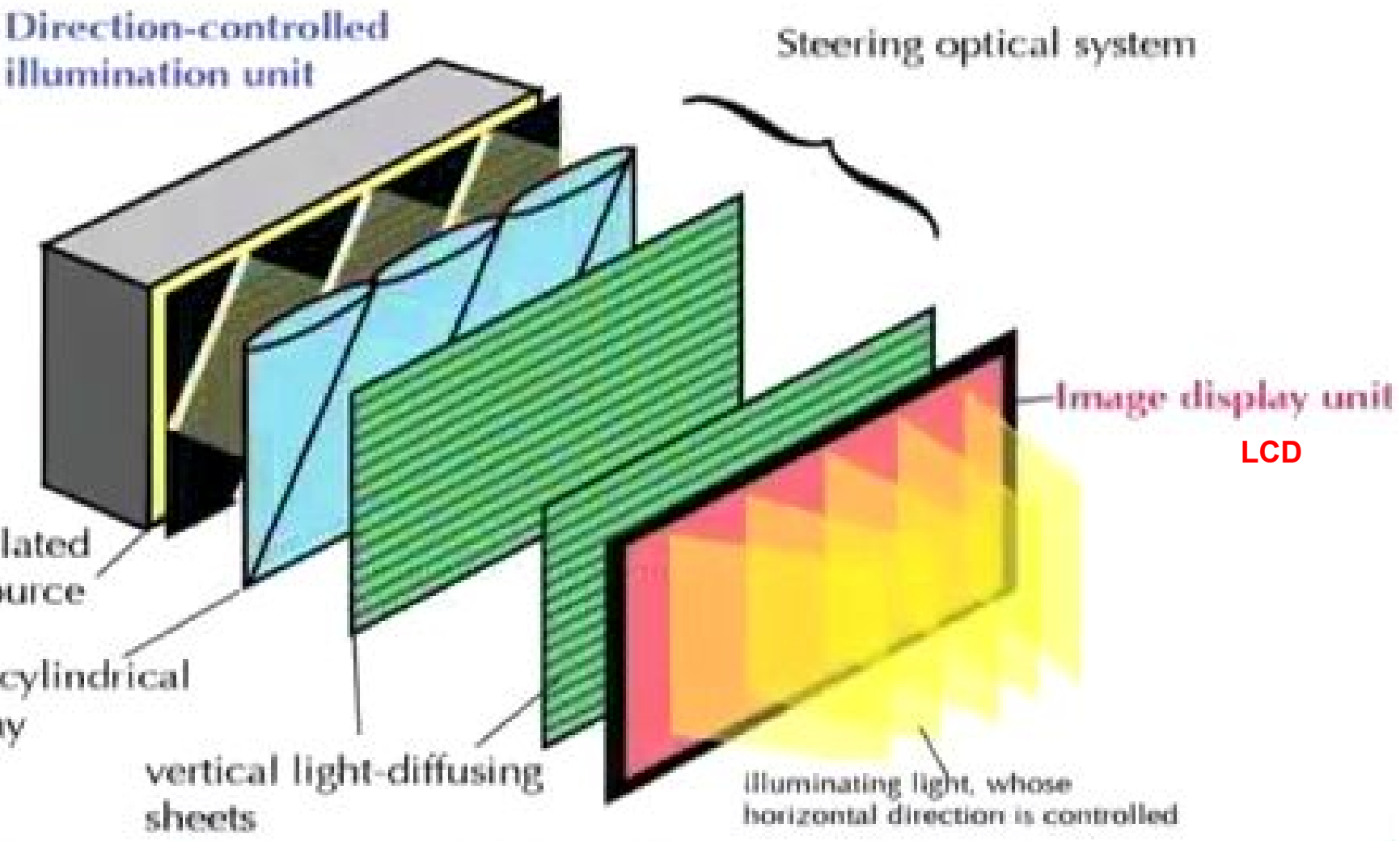


## Purpose of this study

- We propose an **auto-stereoscopic display** method based on the principle similar to the MUTED method utilizing **continuous optical elements** for steering light instead of discontinuous optical elements to **improve illumination nonuniformity**,
- Maintaining the characteristics similar to MUTED, such as **high resolution and large image size, no restriction on viewing position within certain limited region, availability of multiple viewers, and compact system configuration.**
- Confirmation of the validity of the proposed method by an experimental system.
- Consideration for suppressing nonuniform illumination

Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# 2. Working Principle

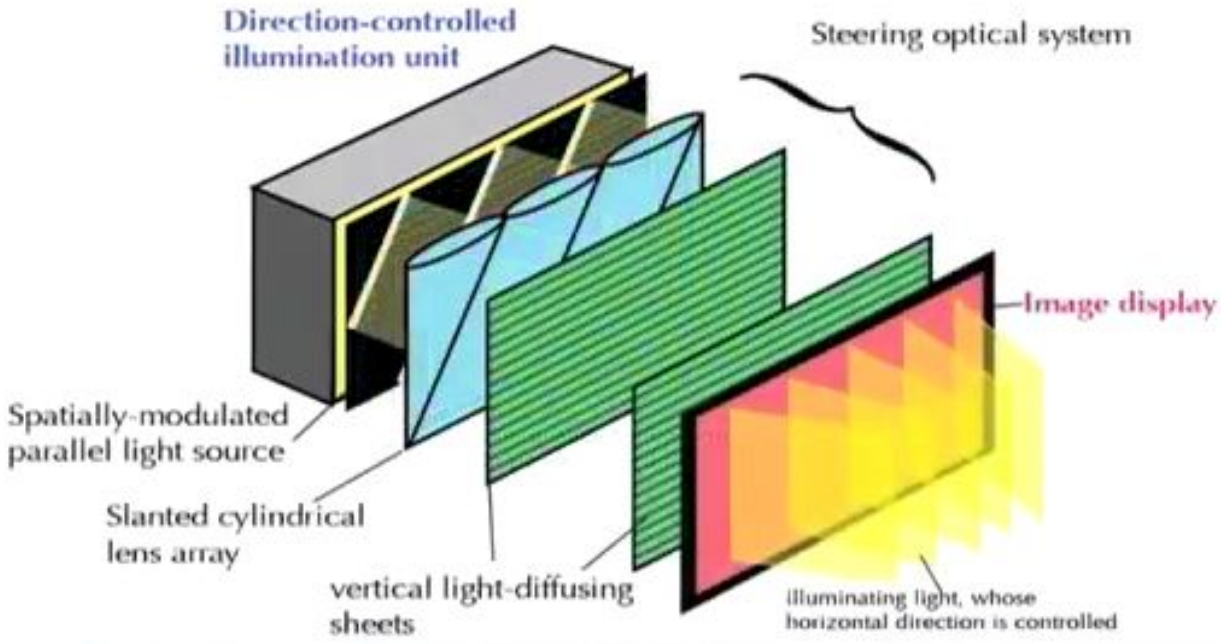



Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# Direction-Controlled Illumination Unit

- **Spatially-modulated parallel light source**
  - spatial light modulation (intensity, color) to produce "control pattern" of emitted light, e.g. via projector
  - e.g. fresnel lens to make parallel
- **Steering optical system**
  - slanted cylindrical lens array deflects horizontally
  - vertical light-diffusing sheets

**"Control pattern"** determines where on cylindrical lens light is projected, thus how it is deflected, thus where the exit pupil is formed!

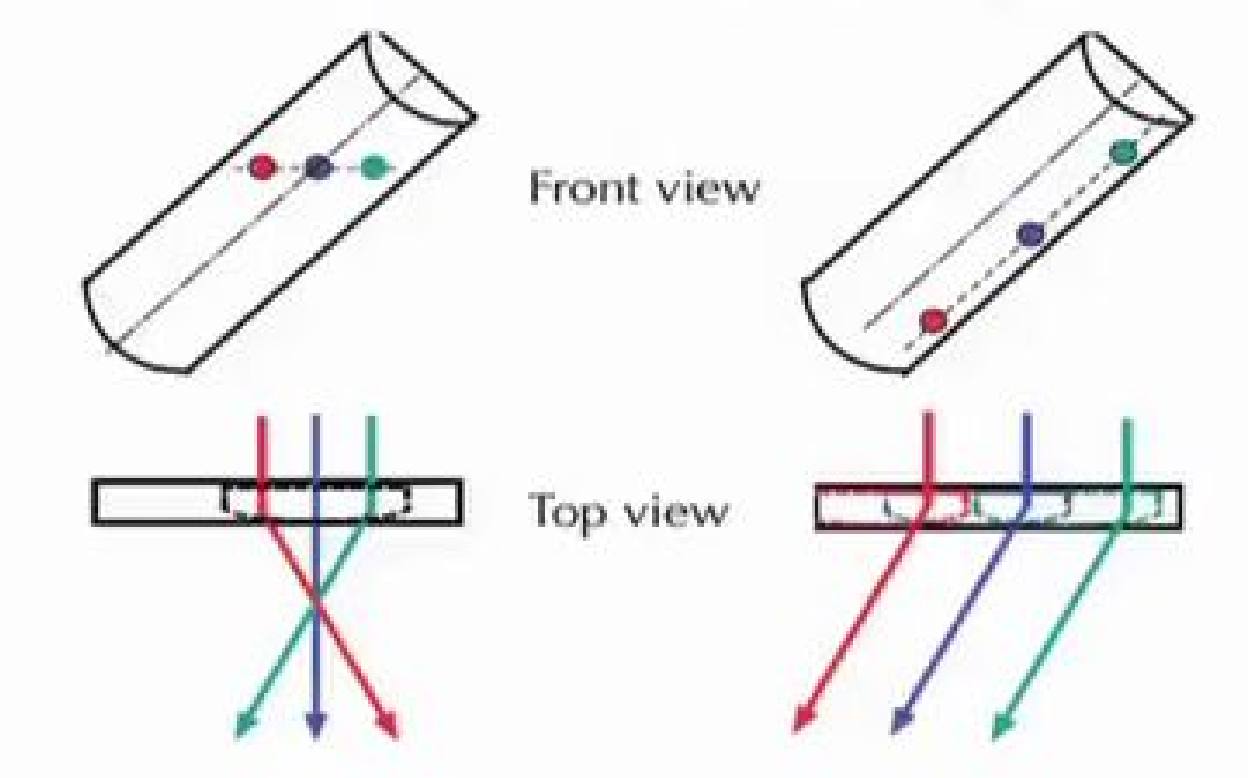




Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# Horizontal Light Deflection by Slanted Cylindrical Lens

- Deflection angle depends on distance to lens centerline
- RGB have different horiz. positions, but should be same angle/dist.
  slanted lenses allow different horiz. positions at same angle/dist.

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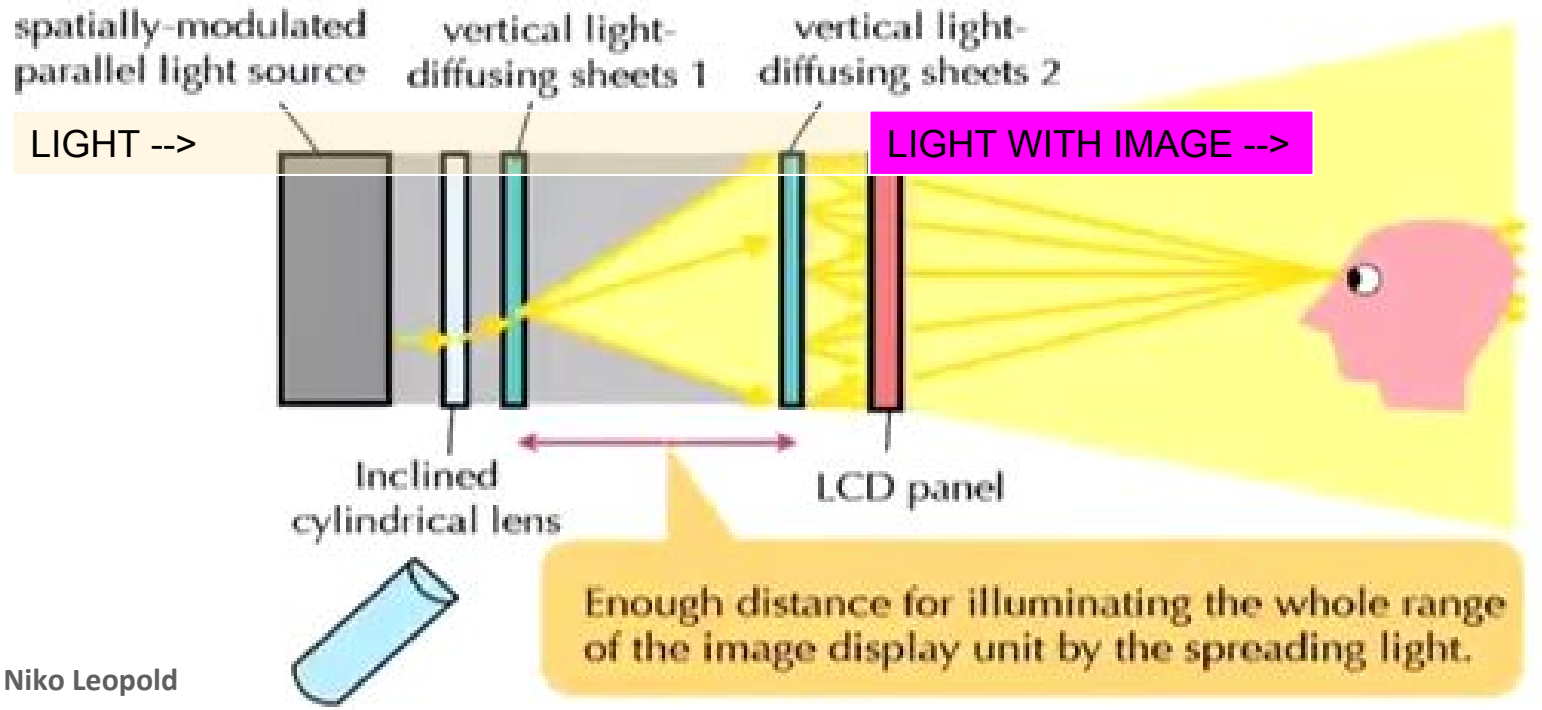
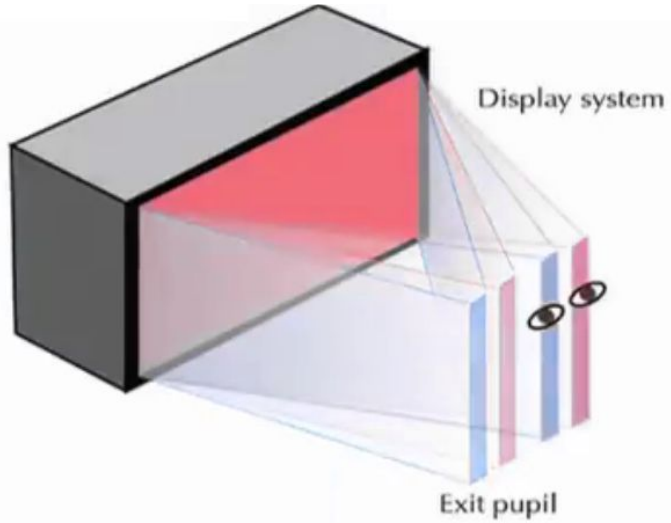
# Spreading Light in Vertical Direction

- After horizontal deflection by cylindrical lens array, light is diffused vertically
- First vertical light-diffusing sheet: Let light cover whole LCD height
  - Single line of control pattern light is enough to transport whole image
  - Each light point on the line produces a vertical light slab that illuminates a vertical pixel column of the LCD image
- Second vertical light-diffusing sheet: Deflect light vertically to observer



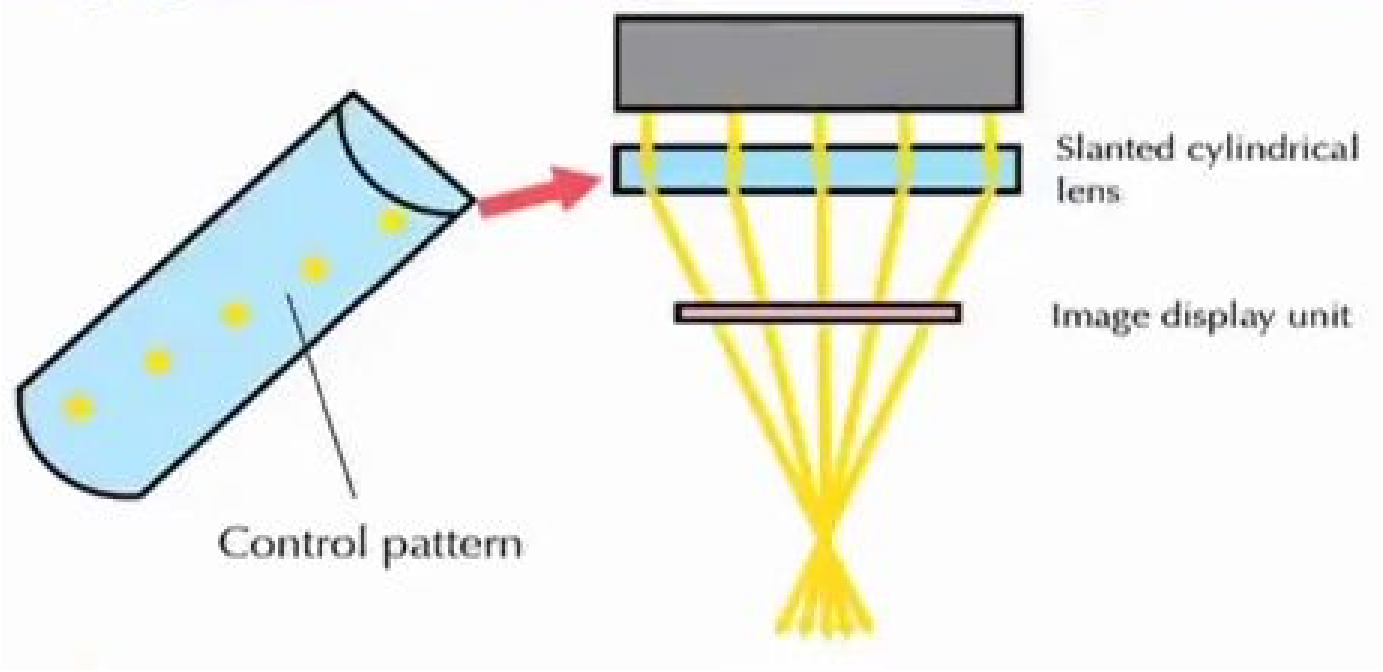

horizontal deflection, vertical diffusion

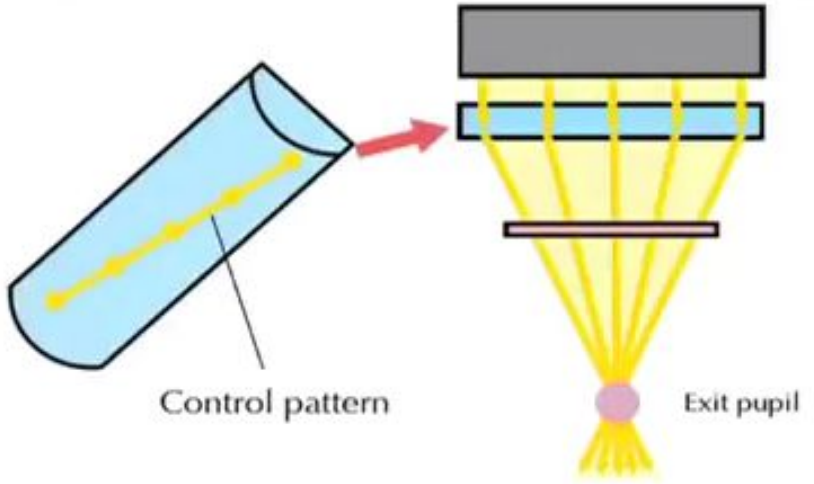



Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# Control Pattern and Horizontal Exit Pupil Location

- Control pattern from projector determines where light hits on lens array, thus how much it is deflected horizontally.
- Using control pattern we can shoot deflected vertical light strips through the LCD image and concentrate image at arbitrary horizontal exit pupil position.

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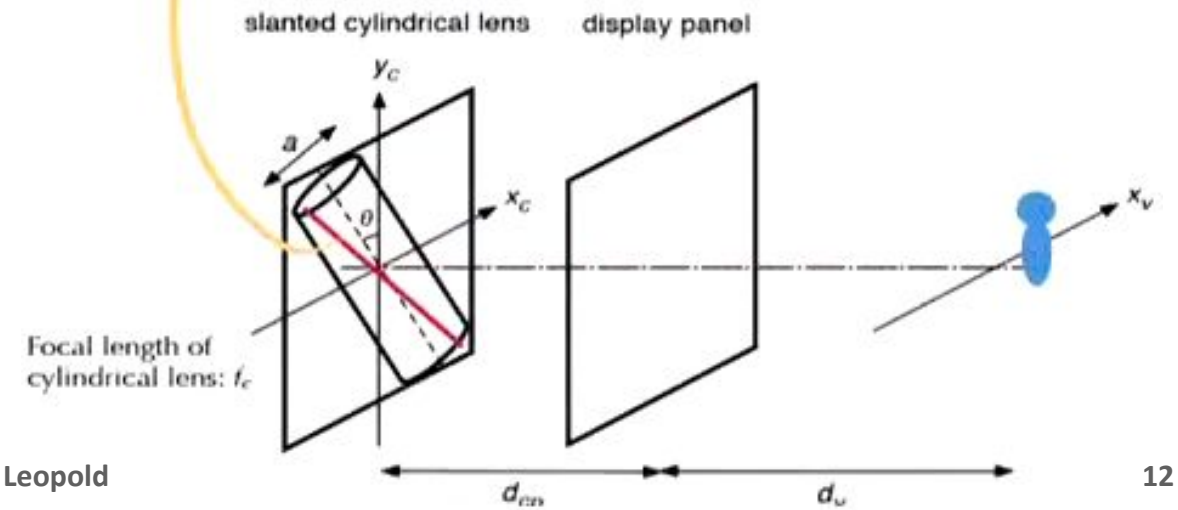
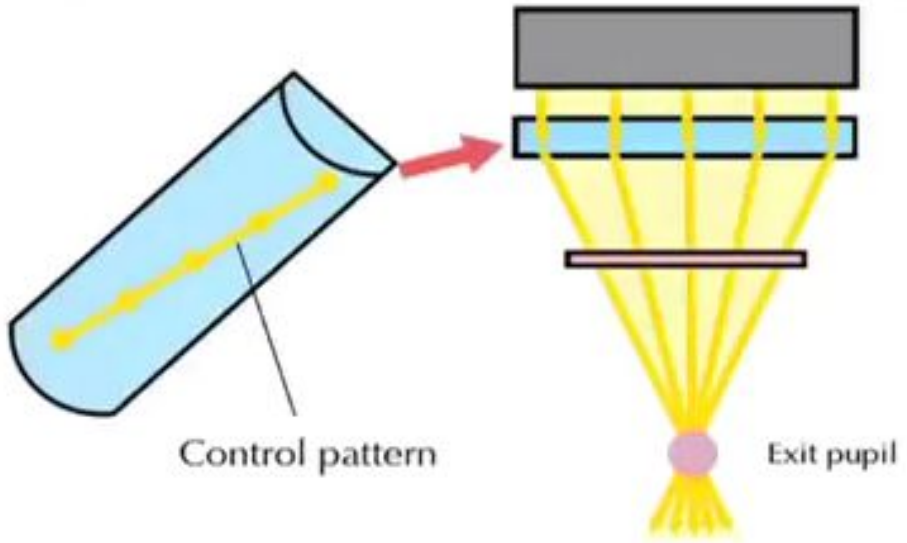
# Control Pattern and Horizontal Exit Pupil Location (2)

- Inclination of control pattern from lens centerline determines exit pupil depth
  => CP parallel to centerline: No deflection, all rays parallel, infinite depth
  => CP inclinated from centerline: No deflection in center, more deflection to the sides, rays form a focus at depth depending on CP inclination
- Lateral shift of CP determines lateral shift of exit pupil

$$y_c = \frac{(d_v + d_{cp})\cos^2\theta - f_c}{(d_v + d_{cp})\sin\theta\cos\theta} x_c + \frac{f_c x_v}{(d_v + d_{cp})\sin\theta\cos\theta}$$

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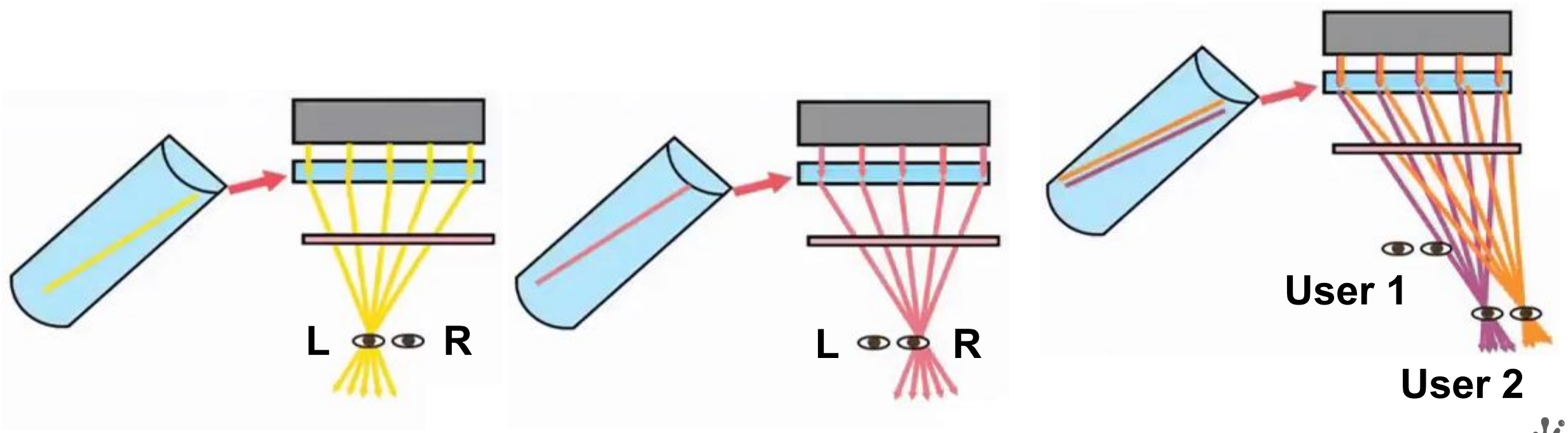
# Auto-stereoscopic View for Multiple Viewers

- For parallax, simultaneously switch LCD image and control pattern (exit pupil), e.g. in time alternate for left and right eye: **L R L R L R…**
- For multiple users, just add more images and control patterns (exit pupis), e.g. **$L_1$ $L_2$ $R_1$ $R_2$ $L_1$ $R_2$…**
- Max. possible number of viewers depends on max. possible frequency

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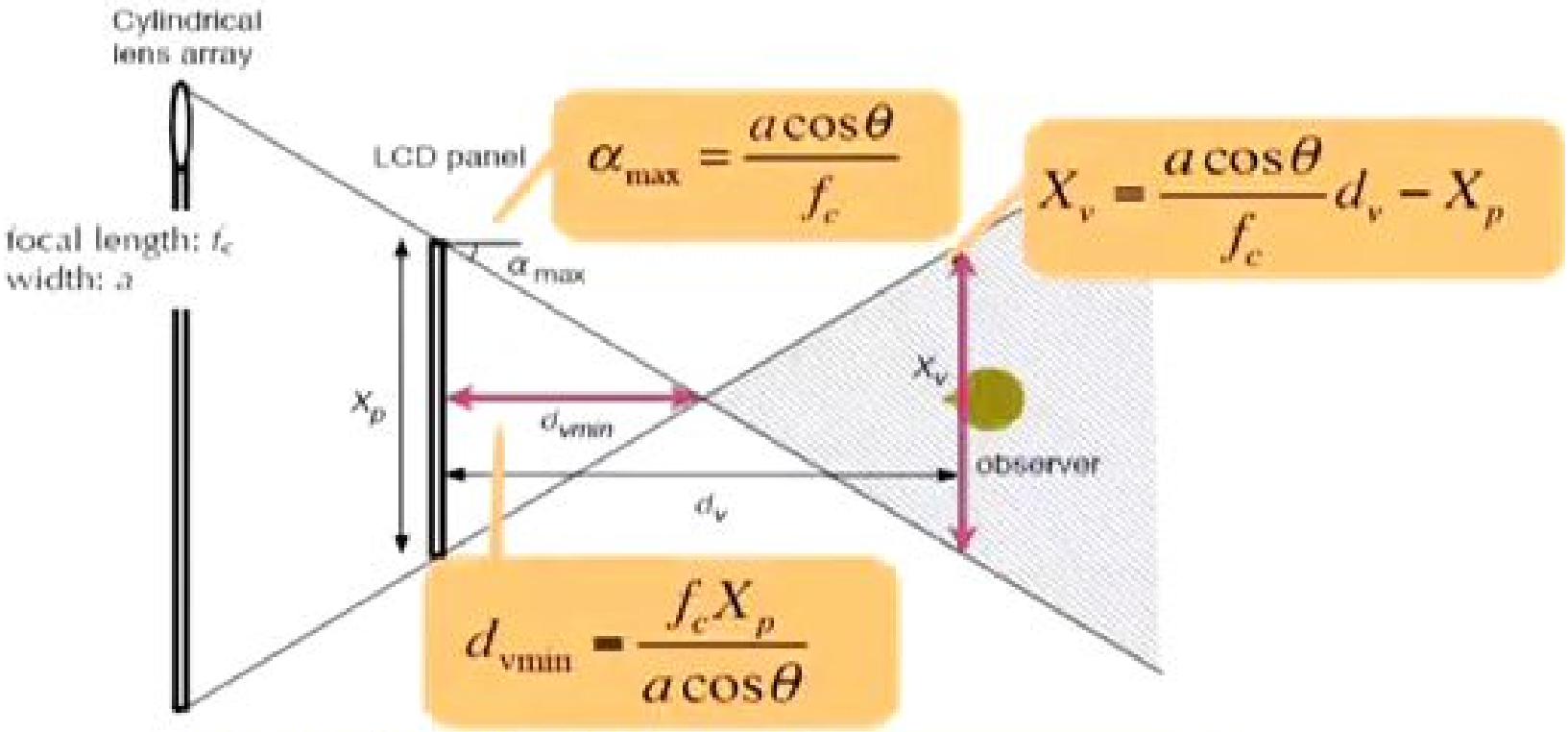
# Viewing Region

- Viewing region depends on maximum deflection angle of cylindrical lens array

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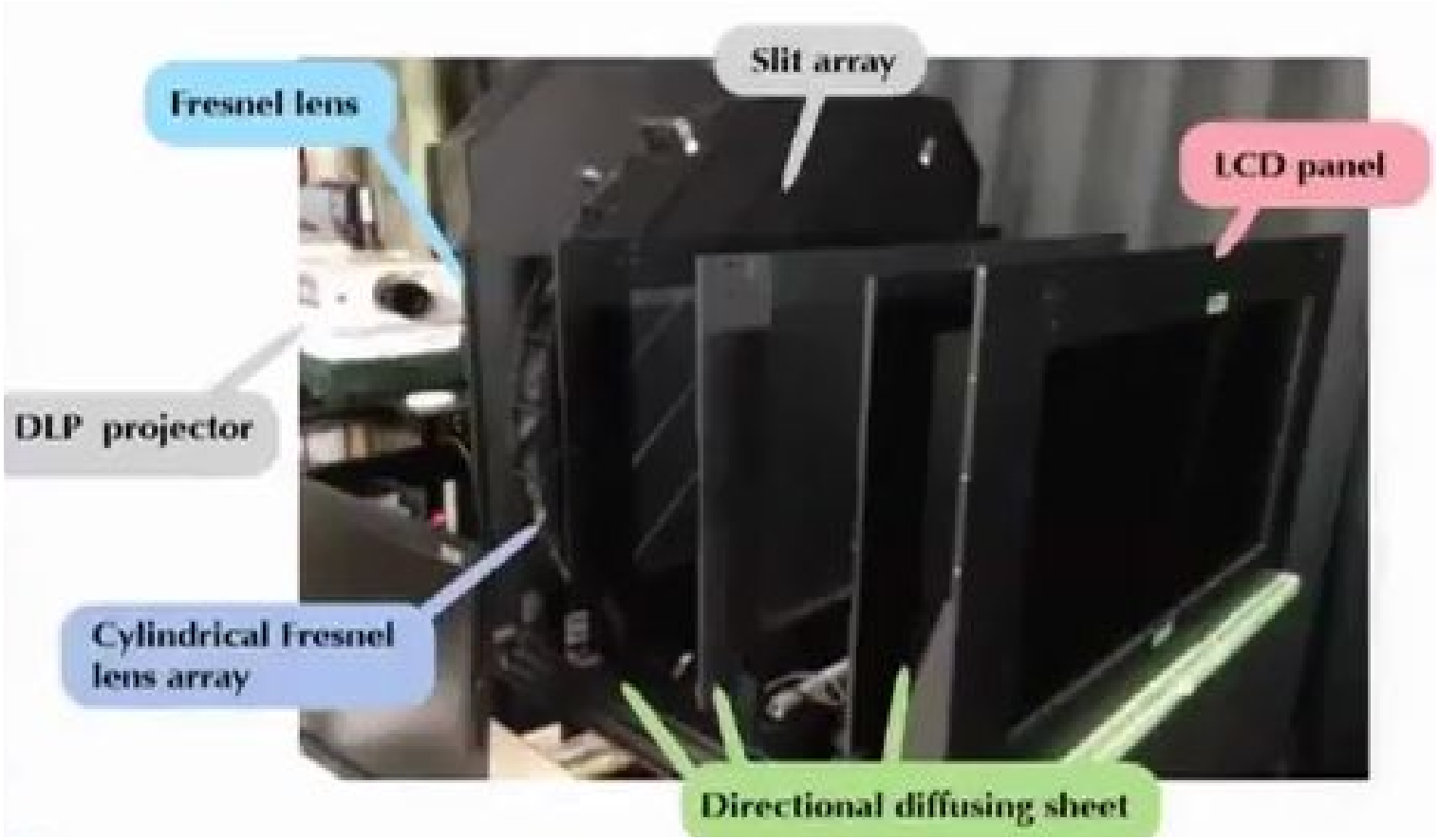
# 3. Experimental Setup and Results

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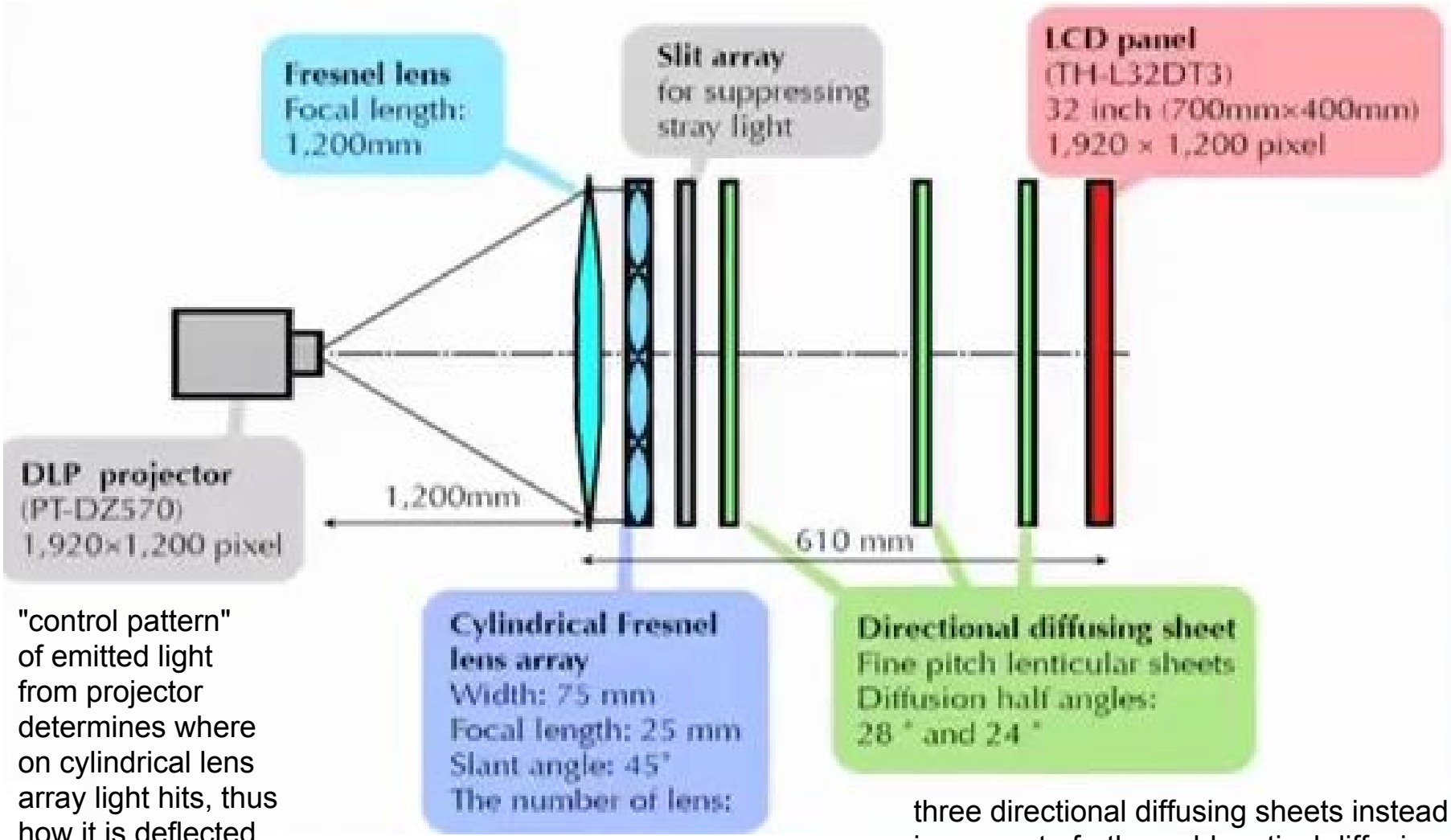
# 3. Experimental Setup and Results (2)




"control pattern" of emitted light from projector determines where on cylindrical lens array light hits, thus how it is deflected and thus where the exit pupil is formed

three directional diffusing sheets instead of two as in paper, to further add vertical diffusion and lessen moiré effect from other two

Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# 3. Experimental Setup and Results (3)

- one display, multiple exit pupils showing at different positions for both eyes
- images observed only at the exit pupils
- 80° viewing angle, 0.4° angular resolution of light direction

(a) (b)

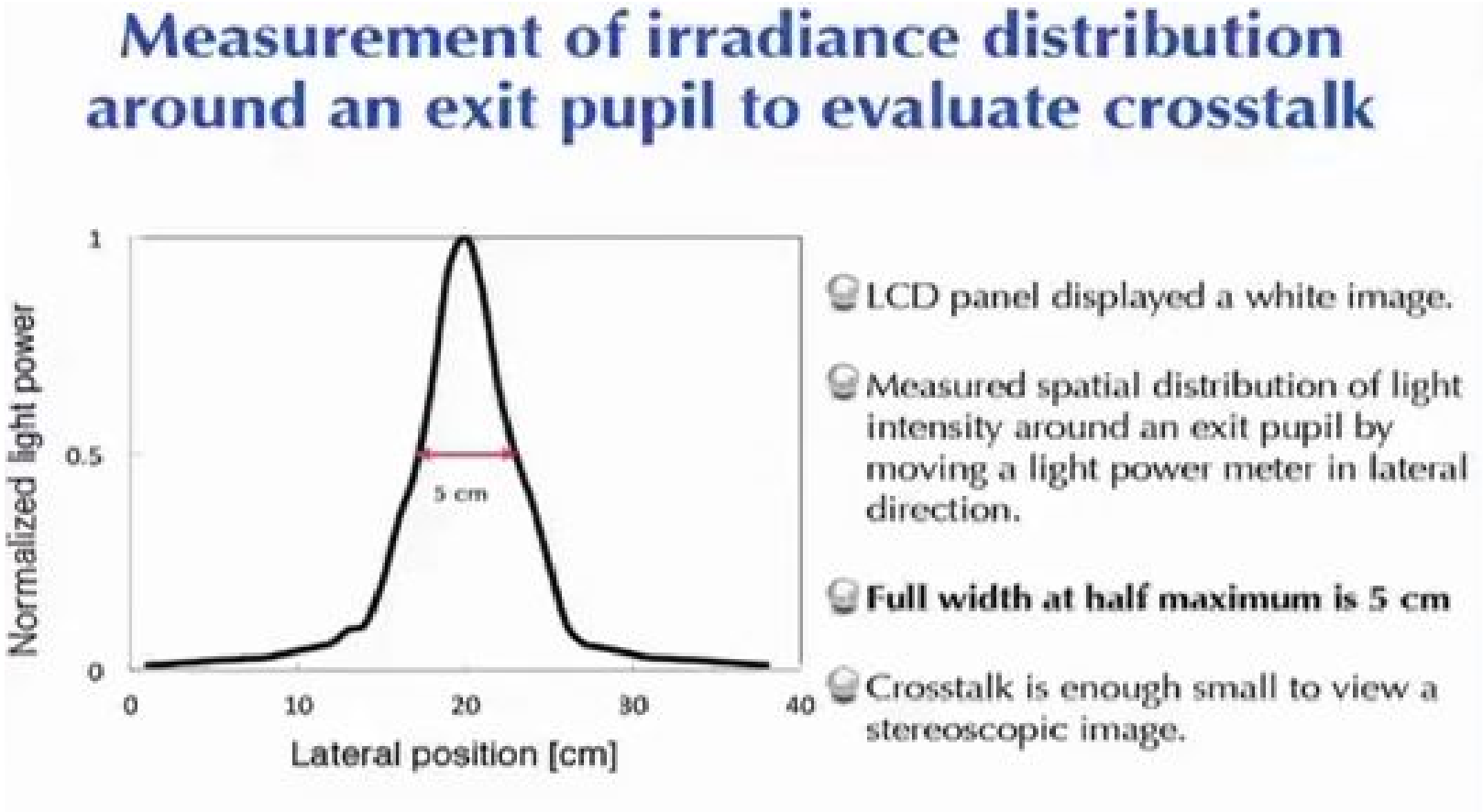
Figure 8 Pictures of images displayed by the experimental system taken at corresponding position of exit pupils; (a) Image for left eye and (b) for right eye.



2014 Miyazaki et al

# Exit Pupil Crosstalk Evaluation

- crosstalk (irradiance mixing) between exit pupils must be small enough so that information for different eyes does not notably mix

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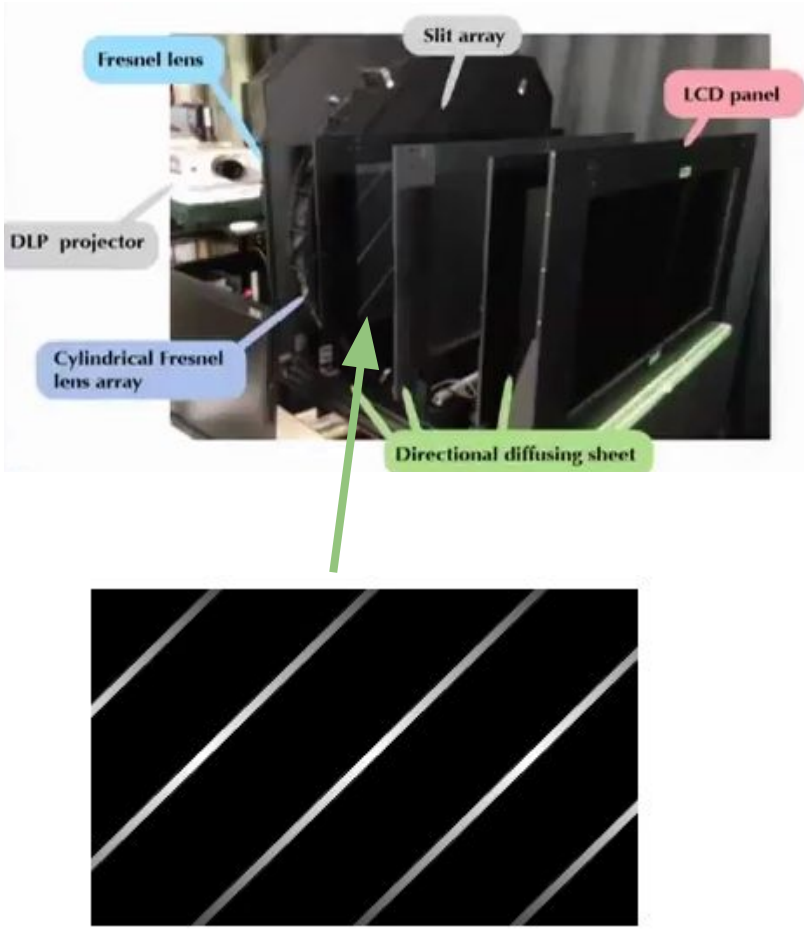
# Improving Illumination non-uniformity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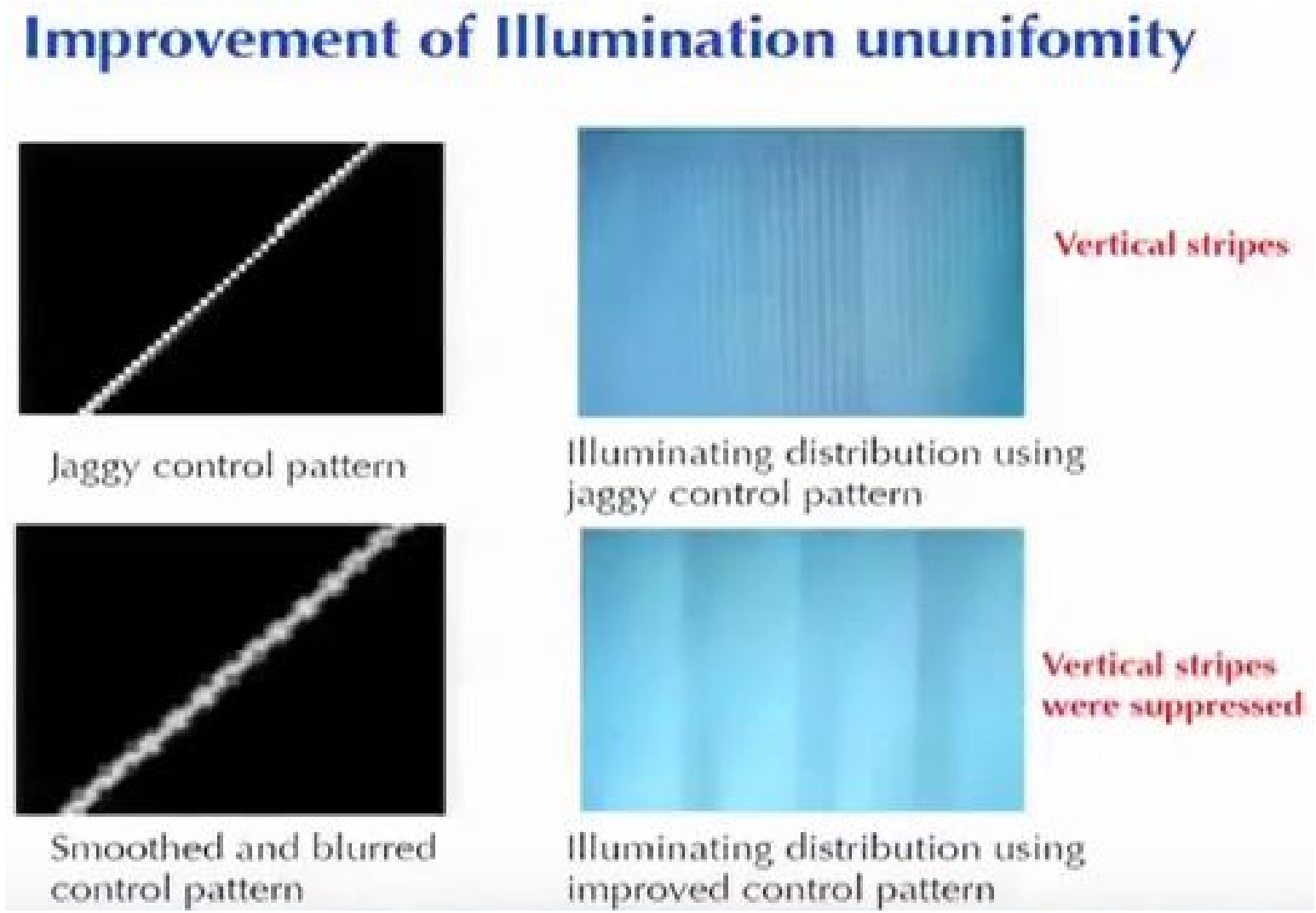
# Improving Illumination non-uniformity (2)




anti-aliasing

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# 4. Future Work

- Implementation of head tracking system
  => stereo camera and face recognition
- Improve light power utilization efficiency
  much less bright pixels than dark pixels in control pattern
  => spatially switchable light source to only emit for bright pixels
- More compact spatially-modulated parallel light source
- Further improve illumination uniformity



Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk

# Summary

What we want: Multi-user Auto-stereoscopic display

- **Auto-stereoscopic:** No need to put on 3D glasses
- **Multi-user:** Possible to experience the 3D effect from multiple angles

Proposed Solution:

“direction-controlled illumination using a slanted cylindrical lens array”

Pattern of projected light determines where rays hit on cylindrical lens array, and thus how much light is deflected horizontally.
We can shoot deflected vertical light strips through the LCD image and concentrate image at arbitrary horizontal exit pupil position.
Alternating patterns and LCD images allow parallax and multiple users.

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# Thank you.