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


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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
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

- **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=espfnKkF5Vk
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

![Auto-stereoscopic display that forms exit pupils for both eyes](image)

*Image illuminated on LCD depends on head position*

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*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 head tracking

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

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.
2. Working Principle

- Direction-controlled illumination unit
- Steering optical system
- Image display unit

E.g., Projector + Fresnel lens to make parallel

LCD

Spatially-modulated parallel light source
Slanted cylindrical lens array
Vertical light-diffusing sheets
Imitating light, whose horizontal direction is controlled
• 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!
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.

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

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.

Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk
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 inclined 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
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: \( \text{L R L R L R...} \)
- For multiple users, just add more images and control patterns (exit pupils), e.g. \( \text{L}_1 \text{L}_2 \text{R}_1 \text{R}_2 \text{L}_1 \text{R}_2... \)
- Max. possible number of viewers depends on max. possible frequency
Viewing region depends on maximum deflection angle of cylindrical lens array.
3. Experimental Setup and Results

![Experimental Setup Diagram](image-url)

- Fresnel lens
- Slit array
- LCD panel
- DLP projector
- Cylindrical Fresnel lens array
- Directional diffusing sheet

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

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.
Exit Pupil Crosstalk Evaluation

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

**Measurement of irradiance distribution around an exit pupil to evaluate crosstalk**

- LCD panel displayed a white image.
- Measured spatial distribution of light intensity around an exit pupil by moving a light power meter in lateral direction.
- Full width at half maximum is 5 cm.
- Crosstalk is enough small to view a stereoscopic image.
Improving Illumination non-uniformity

Original control pattern

Illuminating distribution using original control pattern

Gradated control pattern

Illuminating distribution using gradated control pattern

Luminance steps caused by nonuniformity of diffusing light distribution

Daisuke Miyazaki, https://www.youtube.com/watch?v=espfmKkF5Vk
Improving Illumination non-uniformity (2)

anti-aliasing

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