Foveated Contact Lens Display for Augmented/Virtual Reality

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Customarily, near-eye displays (NEDs) are mounted on a helmet or eyewear [1]. In this work, we attempt to shift this paradigm by building the infrastructure directly on top of the eye. Since the jargon NED is not applicable or at least inaccurate for our case, we shall re-name this type of display as contact lens display (CLD) [2]. The proposed CLD consists of two components, *i.e.* a contact lens and a collimated light-emitting diode (LED) array, as shown in Fig. 1. Adjacent to the cornea is a thin layer of contact lens for fixing the refractive errors. On top of the contact lens is an array of LEDs, each pixel of which is able to emit a collimated beam of light towards the center of lens of eye. It is required that the etendue of LED be adequately small so that a clear image would be formed on the retina.

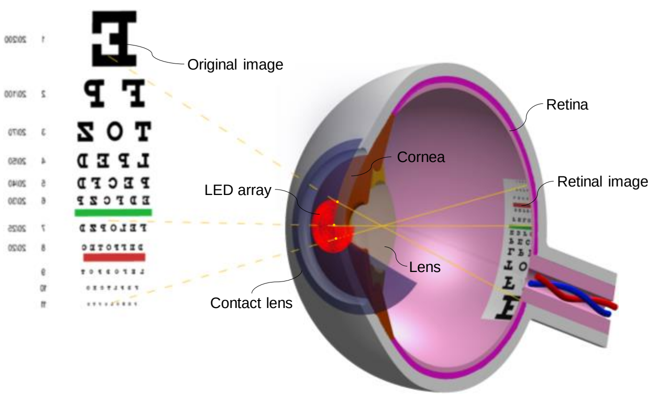


Figure 1. Schematic drawing of the proposed CLD.

The concept of foveated imaging originates from the computer graphics, which is intended to speed up the rendering of high-resolution images. However, the physical resolution of the image remains intact, and an additional device to track the eye is needed. Alternatively, this concept can be realized by re-arranging the pixels to match with the distribution of cones as these photoreceptor cells are clos ely linked to the visual acuity. For the resolution of our CLD is foveated, so is its angular resolution. If measured in arcminute (′), the angular resolution for the i^{th} ring of the field angle θ can be calculated with

$$Angular\ resolution = \frac{21600 \sin\theta}{N_i} \quad (1)$$

where N_i is the number of LEDs along the i^{th} ring. As shown in Fig. 2, the best angular resolution is 0.38′ at 0°, whereas the worst is 3.11′ at −41°.

To evaluate the device performance, numerical simulations have been carried out. Fig. 3 shows the original image alongside the real and virtual images formed on the retina. As expected, the virtual image is sharper and less distorted than the real image especially at the marginal fields.

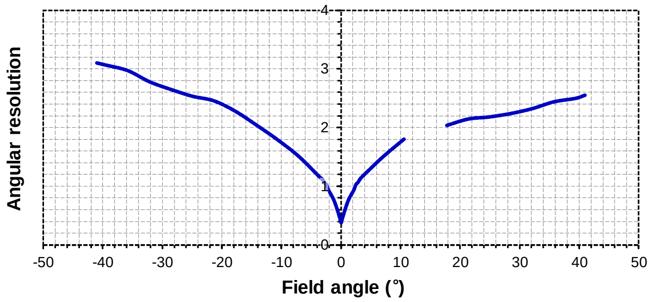
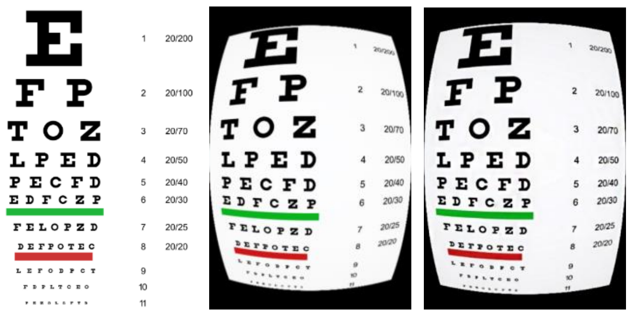


Figure 2. Angular resolution versus the field angle.



(a) (b) (c)

Figure 3. (a) Original image, (b) real image, and (c) virtual image.

In summary, for the real image, modulation transfer function (MTF) is 0.669757 at 30 cycle/degree, contrast ratio (CR) is 5, and distortion is 10%. For the virtual image, field of view (FOV) is 82°, best angular resolution is 0.38′, MTF is above 0.999999 at 30 cycle/degree, CR is 4988, and distortion is 6%. Compared to the retinal-projection-based NEDs, our CLD has several advantages. First, eye is allowed to move or rotate freely without the help of exit pupil expansion nor eye tracking. Second, the physical resolution is foveated to match with the distribution of cones. This will significantly reduce the total number of pixels as well as the latency incurred by the image processing. Third, no burden or weight on the head and no worries about head-related human factors, such as the shape of head, interpupillary distance *etc*.

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References

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[2] J. Chen, L. Mi, C. P. Chen, H. Liu, J. Jiang, and W.

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