Vision-Correcting Display with Microlens Array

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ABSTRACT

We introduce a new vision-correcting display for hyperopia (far-sightedness). We place a microlens array in front of the display of a digital device to form a virtual image at a depth on which hyperopic patients can easily focus.

1 Introduction

Many people get stressed over the visual aberrations such as cataract, myopia, and hyperopia [1]. These aberrations are typically corrected by eyeglasses, contact lenses, and refractive surgery. However, these correction techniques force us to constantly wear optical glasses or expose us to the risk of eye damage. Apart from these techniques, vision-correcting displays (VCDs), which require no glasses and surgery, recently attract a lot of attention. Aligned with this trend, we propose a method of correcting hyperopia on the display side.

Figure 1 illustrates the mechanism of hyperopia, which is also called far-sightedness. The light rays from a point object pass through the crystalline lens, and converge at the focal plane. However, in the eyes of hyperopic patients, the focal plane is located apart from the retinal surface. The point object is thus defocused and blurred over the red region.

Alonso et al. [2] proposed a VCD technique that aims to invert the defocus effect. The defocus effect was modeled as convolution with a point spreading function (PSF), and canceled by deconvolving the PSF. However, this method required the exact shapes of the PSF and its inverse. Moreover, the deconvolution was usually an ill-posed problem. Due to these issues, it was difficult to attain high-quality vision correction with this technique.

Huang et al. [3] proposed another VCD technique using a light field display. By displaying an appropriate light field, they aimed to form a clear image on the patient's retinal surface. Although the approach was theoretically reasonable, the light field display was implemented using a pinhole mask, which significantly reduced the brightness.

To avoid the deconvolution and the brightness issues, we propose a new VCD method using a microlens array, instead of a pinhole mask. Figure 2 illustrates the concept of our approach. The key idea is to form a virtual image at a depth on which the hyperopic patient can easily focus. For example, the display is located at 300 [mm] from the patient's eye, but the virtual image is created at 400 [mm], at a depth where the patient can clearly see. This design would help elderly people to see personal digital devices without stretching out their arms.

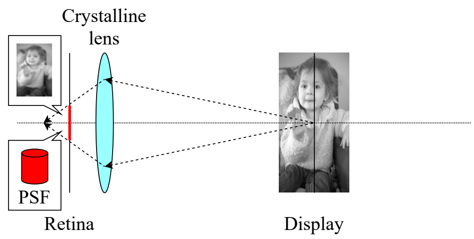


Figure 1: Mechanism of hyperopia.

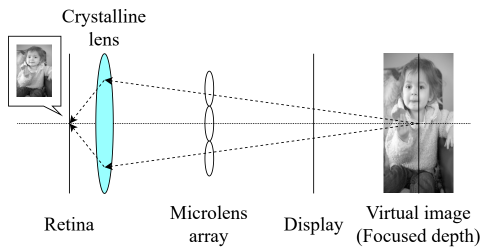


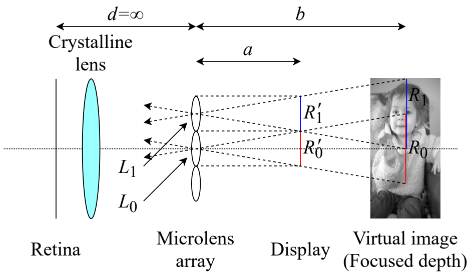
Figure 2: Concept of our approach.

2 Proposed method

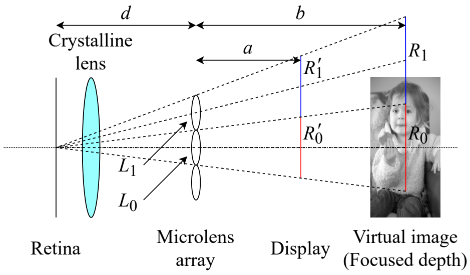
2.1 Image computation

We first prepare a target image that should be perceived by the hyperopic patient. The goal of our method is to present this target image as a *virtual image* created at the focused depth of the patient, as shown in Fig. 3. The virtual image is formed collectively by each of the small lenses in the microlens array. Let f [mm] be the focal length of the microlenses, which is located a [mm] ($a < f$) apart from the display surface. The virtual image is created at b [mm] behind the microlens, following the lens formula: $1/a+1/b = 1/f$. Our interest is in the case of $a \ll b$ because we aim to locate the virtual image as far as possible.

We mention how to compute an image to be presented on the display. Each microlens L_i should create a portion of the target image R_i as a virtual image at the focused depth as shown in Fig. 3. Inversely, region R_i should be the virtual image created by L_i from a portion on the display R'_i. Therefore, the texture of R_i should be presented at R'_i.



(a) $d = \infty$



(b) $d < \infty$

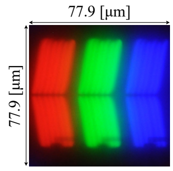
Figure 3: Detail of our method.

In this manner, we determine what should be presented at R_i' for all the microlenses, and compute the entire image to be presented on the display. In this process, we need to downsample the target image because $R_i' : R_i = a : b$.

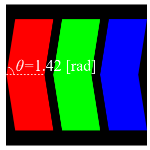
We present geometrical configurations to further clarify how R_i and R_i' are assigned to each microlens L_i. This assignment involves three steps. First, we determine the center of R_i' on the display surface considering the position of L_i. Then, the display surface is evenly divided by $\{R_i'\}$. Finally, the corresponding R_i is determined from R_i'. Note that R_is overlap each other on the virtual image. We now describe the detail of the first step. As shown in Fig. 3, we consider two configurations with infinite/finite distances d between the eye position and the microlens array. In both cases, we consider the light ray that passes through the center of each microlens L_i. We assign R_i' so that the light ray passes through the center of R_i'. When $d = \infty$ as shown in Fig. 3(a), we consider the light rays that are perpendicular to the display surface. Therefore, R_i and R_i' are assigned along the parallel lines. Meanwhile, when $d < \infty$ as shown in Fig. 3(b), we consider the light rays that converge to the eye position. Therefore, R_i and R_i' are assigned along the slanted lines. In other words, angular compensation (AC) is applied for the latter case.

2.2 Microlens-array fabrication

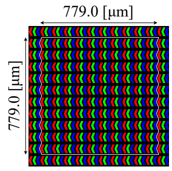
Figure 4 illustrates our implementation of the microlens array. Figure 4(a) shows a single pixel of iPhone 11, whose size was 77.9 [μm] × 77.9 [μm]. We first approximated the shape of the pixel as in Fig. 4(b), where we introduced an angular parameter $\theta = 1.42$ [rad]. We then designed the microlens array so that 10 × 10 pixels were covered by one microlens. We set the focal length of the microlens to 11 [mm]. Figure 4(c) illustrates our microlens model, where the region bounded by the white lines corresponds to the pixels covered by one microlens. Figure 4(d) shows a fabricated microlens array, and Figure 4(e) is an enlarged view of a lens boundary. We observed the microlens array located in front of iPhone 11 to confirm the pixel-to-lens alignment, as shown in Fig. 4(f). Here, we displayed a alternating black-and-white pattern on iPhone 11. We noticed that color moire was generated along a lens boundary, whose correction remains as one of the future works.



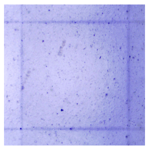
(a) Pixel structure



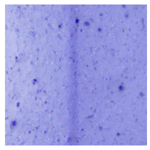
(b) Pixel model



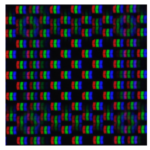
(c) Microlens model



(d) Microlens (impl.)



(e) Enlarged



(f) Microlens + iPhone

Figure 4: Implementation of microlens array.

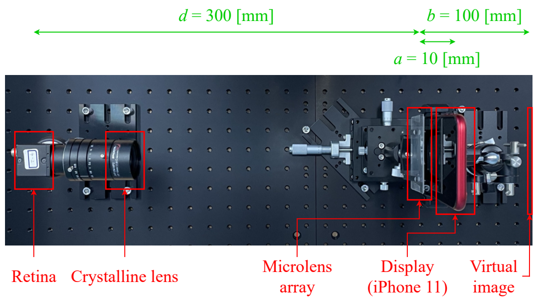
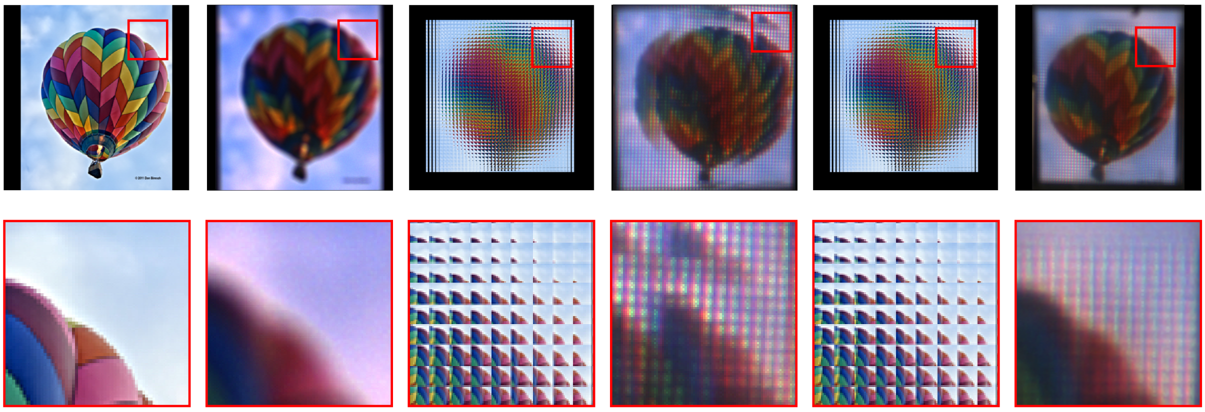


Figure 5: Implementation of our VCD.

3 Experimental result

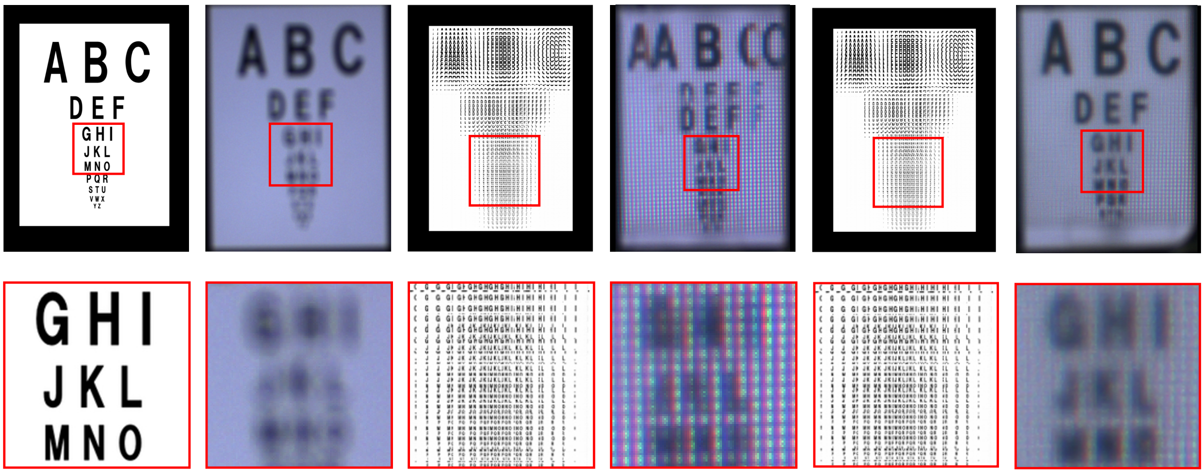
Figure 5 shows our experimental setup, where a camera (POINT GREY, FL2-08S2C) was used to simulate an eye of a hyperopic patient. The focal length of the lens mounted on the camera (SPACE, JHF12M-MP2) was 12 [mm], and the F-number was F1.8. We adjusted the camera to be focused on 400 [mm] ahead, and we placed the display (iPhone 11) at 310 [mm] from the camera, which is 90 [mm] closer than the focused depth.

To correct hyperopia by our VCD method, we placed the microlens array in front of the display. The microlens array was located a = 10 [mm] apart from the display, which



(a) Original (b) Baseline (c) Displayed w/o AC (d) Observed w/o AC (e) Displayed with AC (f) Observed with AC

Figure 6: Observed *balloon* images.



(a) Original (b) Baseline (c) Displayed w/o AC (d) Observed w/o AC (e) Displayed with AC (f) Observed with AC

Figure 7: Observed *alphabet* images.

was 300 [mm] apart from the camera. The virtual image should be formed at $b = 100$ [mm] behind the microlens array because it should be located at 400 [mm] from the camera. The focal length of the microlenses, 11 [mm], was suitable for this configuration according to the lens formula. The displayed images were computed as mentioned in Section 2.1. We compared three cases, where the original image was presented without the microlens array (baseline), and the computed image was displayed through the microlens array (ours) with and without AC. Figures 6 and 7 show several results of our VCD method. In both figures, (a) are the original images to be perceived, (b) are the images perceived by the hyperopic eye (baseline). Shown in (c) are the computed images that were presented on the display, and (d) are the results of the observations through the microlens array. In (c) and (d), we did not apply AC, which resulted in poor visual quality. Meanwhile, in (e) and (f), we applied AC considering the eye position. As shown in (f), the observed images are clearer and sharper than the baseline without vision correction (b). Moreover, the brightness of (f) was equivalent to that of (b); our method does not suffer from the brightness issue unlike the previous approach [3].

4 Conclusion

We introduced a new vision-correcting display for hyperopia. We placed a microlens array in front of the display of a digital device to form a virtual image at a depth on which patients can easily focus. One of the future works is an analysis of color moire, which will be accomplished based on the Zernike analysis [4].

References

[1] J. F. Salmon, Kanski's Clinical Ophthalmology (9th ed.), Butterworth Heinemann, 2020.

[2] M. Alonso and A. B. Barreto, "Pre-compensation for high-order aberrations of the human eye using on-screen

image deconvolution," in *Proc. IEEE Engineering in Medicine and Biology Society*, pp. 556–559, 2003.

[3] F. C. Huang, G. Wetzstein, B. Barsky, and R. Raskar, "Eyeglasses-free display: towards correcting visual aberrations with computational light field displays," *ACM Trans. Graph.*, vol. 33, no. 4, 2014.

[4] F. Zernike, "Beugungstheorie des schneidenver-fahrens und seiner verbesserten form, der phasenkontrastmethode," *Physica*, vol. 1, no. 8, pp. 689–704, 1934.