Compensation of a chromatic aberration of a geometric phase lens for realizing a bi-focal integral floating display without a color breaking

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Abstract—A bi-focal geometric phase (GP) lens can be used to improve the depth range of an integral floating display to form switchable depth planes. However, due to a chromatic aberration of a GP lens to form R/G/B sub-images at different locations, a color breaking of floated image can occur. In this paper, we propose a novel method to compensate that chromatic aberration by integrating R/G/B pixels at depths.

Keywords—chromatic aberration, geometric phase lens, integral floating display

A geometric phase (GP) lens is a device to have a polarization dependent bi-focal property. Since the focal length of the GP lens can be switched using an active retarder such as a liquid crystal (LC) cell, the GP lens is expected to be widely used to enhance the performance of various display applications. Among them, an integral floating display to provide integrated 3D space using a combination of a lens array and a floating device is an appropriate candidate since the center location of the integrated 3D space is a focal plane of the integral floating optics [1-2]. Thus, a GP lens can be used as a floating device to extend the depth range of the conventional integral floating display with its bi-focal planes [3].

However, the current commercially available GP lens has a bottleneck of image degradation due to a chromatic aberration which means that the focal lengths of the GP lens for red(R), green(G), and blue(B) sub-image are different. The focal lengths of the GP lens for different color (R/G/B) were determined by the diffraction angle ($\theta$) in equation 1, as follow [4-5].

$$\theta = \sin^{-1}\left(\frac{\lambda}{2x\Lambda}\right),$$

(1)

where, $\theta$ is diffraction angle, $\lambda$ is the wavelength, and $\Lambda$ is the period of interference. As a result, a color breaking problem can occur as shown in Fig. 1. In Fig. 1, though the R/G/B sub-images are integrated at the same plane, they will be floated at different locations due to the chromatic aberration of a GP lens having different focal lengths for R/G/B sub-images. Figure 2 shows the aberration properties of GP lens. Figure 2(a) show the

![Fig. 1. Color breaking of a conventional integral floating display using a GP lens with a chromatic aberration.](image)

![Fig. 2. Chromatic aberration property of the GP lens. (a) Schematics of imaging optical set-up. (b) The captured original image without GP lens. (c) The captured images with GP lens according to the variation of focusing positions.](image)
schematic of the imaging optical set-up. Figure 2(b) shows the captured original image without GP lens. Figure 2(c) shows the captured images with the GP lens at different focusing positions. Three colored characters were focused at different focusing positions due to the chromatic aberration property of GP lens. Thus, a novel method to compensate that chromatic aberration is needed to provide a full color integrated 3D spaces using a commercial GP lens. For that purpose, we propose a method to combine the floated R/G/B sub-images altogether by integrating them at pre-designed depths.

The basic idea to compensate the chromatic aberration is to provide R/G/B sub-images at different depths to consider the chromatic aberration of the GP lens. Since the GP lens has a different focal lengths for the R/G/B wavelengths, it is needed to integrate the R/G/B sub-images at different depths to make them be combined altogether after being floated differently by the GP lens as shown in Fig. 3.

![Fig. 3. Compensation of the chromatic aberration by integrating the R/G/B sub-images at different depths.](image)

In order to achieve the goal above, it is needed to calculated the integrated depths of the R/G/B sub-images independently using the chromatic parameters of the GP lens. The experimental parameters of the demo system with a compensation of the chromatic aberration is shown in Table I. As shown in Table I, the integrated depths of the R/G/B sub-images are set to have the same floating distance.

<table>
<thead>
<tr>
<th>Color of sub-image</th>
<th>Integrated depth (mm)</th>
<th>Focal length of the GP lens (mm)</th>
<th>Floating distance (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Red</td>
<td>44.8</td>
<td>84.6</td>
<td>-95.4</td>
</tr>
<tr>
<td>Green</td>
<td>48.8</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>53.6</td>
<td>122.2</td>
<td></td>
</tr>
</tbody>
</table>

The captured views of a conventional integral floating display with a GP lens and the compensated results are shown in Fig. 4(a) and 4(b), respectively. In Fig. 4(a), though the R/G/B sub-images were integrated at the same image plane, the floated images are showing different magnification and motion parallaxes since they are distributed different floating planes. However, the compensated results shown in Fig. 4(b) with the experimental parameters of Table I provides much a improved depth alignment and almost same motion parallaxes between the R/G/B images.

![Fig. 4. Comparison of the experimental results: (a) conventional integral floating display using a GP lens with a chromatic aberration, (b) compensated results to integrated the R/G/B sub-images at the pre-designed depths.](image)

Therefore, we can conclude that the proposed method improved the imaging performance of the integral floating display with a GP lens by resolving the color breaking problem from the issue of the chromatic aberration of the GP lens.

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