Adaptation of volumeholographic cell arrays to divergent LED illumination

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Volumeholographic cell arrays (VCA) have proven to be a viable solution to form light distributions with incoherent light sources using thin photopolymer films. Yet, in our last contribution, the redistribution of light was only shown for collimated LEDs. In this article we show that illumination with divergent LEDs is possible by adaptation of the VCA to the beam characteristics of the used lightsource.

1 Introduction

Thin photopolymer films [1, 2] seem to be an attractive solution for the usage of volumeholograms in automotive applications regarding 3D- signatures in rear lights [3]. As the material is lightweight and remains almost transclear after processing, the question arises whether they can be used for illumination purposes as well, with the aim to substitute conventional optics like lenses or reflectors. One of the main problems is the optimization of these volumeholograms in such a way, that they can be illuminated with incoherent and divergent lightsources at small distances, which are necessary for automotive applications.

In [4] we showed that light coming from incoherent LEDs can be formed similar to (monochromatic) low-beam distributions by a volumeholographic-cell-array (VCA) approach. But for the VCA to work properly, the LED had to be collimated. Following that, we hereby present a method, utilizing raytracing software that is commonly used for optic design, to adapt VCAs to the specific beam characteristics of the used LED.

2 Adaptation Method

In our case holograms are produced by superimposing two laserbeams, the object- $\boldsymbol{\sigma}$ and the reference-beam $\boldsymbol{\varrho}$, on the photopolymer film. The object-beam carries the necessary phase-information of the VCA, so that the desired light distribution is generated. The reference-beam specifies the direction from where the hologram needs to be illuminated, which is exactly where the adaptation takes place.

Figure 1a shows a whitelight LED with outgoing rays $\boldsymbol{\varrho}$. These rays have to be in accordance with the reference beam during the manufacturing process for the volumeholographic element to work properly. The LED is positioned in front of a VCA, which is represented as a luminance-detector in a raytracing simulation. The detector is divided into $n \times n$ cells, corresponding to the number of array elements within the VCA. In this example there are 32×32 cells with an edge size of $L_{\text{cell}} \approx 0,7\,\text{mm}$ resulting in an total length of $L_{\text{VCA}} \approx 20\,\text{mm}$.

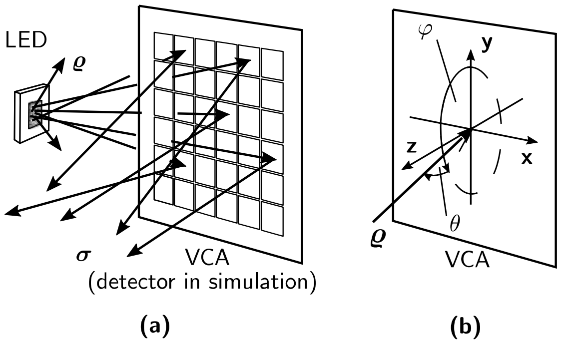

Fig. 1 *(a) Configuration sketch of the VCA as a detector with $n \times n$ cells in a raytracing software and (b) spherical coordinate system of the VCA with azimuth angle φ and elevation angle θ.*

After performing the simulation, the detector contains information about the incoming rays from the lightsource, including direction and location. This information is now rearranged to get one effective ray $\boldsymbol{\varrho}_{\text{eff}}$ for each cell that represents the reference beam during the manufacturing process. The direction of $\boldsymbol{\varrho}_{\text{eff}}$ is calculated by arithmetic means of the components of all lightrays $\boldsymbol{\varrho}_k$ hitting cell (i, j).

$$\boldsymbol{\varrho}_{i,j} = \frac{1}{m} \sum_{k=1}^{m} \boldsymbol{\varrho}_k \tag{1}$$

where m is the number of rays located within face (i, j) of the detector.

For the used LED in figure 1 with a distance of $40\,\text{mm}$ and an incident angle of $\alpha = 50\,\text{deg}$ to the VCA, the resulting reference beam directions for each cell are demonstrated in figure 2. The direction is expressed in spherical coordinates with elevation angle θ (angle of incidence to the VCA-plane) and azimuth angle φ (direction in the VCA-plane), as depicted in figure 1b.

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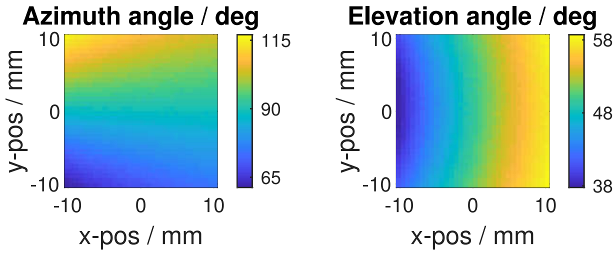

Fig. 2 *Pseudocolor images of the reference beam directions in azimuth and elevation angle, depending on the VCA x- and y- position.*

Due to the Lambert-emission, the elevation angle $\theta \in [20, 65]$ deg changes radial to the LED in an intervall around the angle of incidence α. The azimuth angle $\varphi \in [25, 155]$ deg converges to the lightsource, of which the origin lies on the x-axis in negative y-direction.

3 Experimental Results

For validation of the adaptation method, a reflective VCA with the purpose of generating a low-beam-shaped distribution similar to [4] is produced. But the reference beam directions for each cell are changed corresponding to the angle distribution gathered by the raytracing simulation, instead of using a fixed reference angle as for the case of collimated illumination. After that the VCA is put on the same position as the detector in the raytracing simulation and illuminated by the whitelight LED. The light distribution reflected by the VCA is projected onto a screen which is positioned at a distance of 545 mm beyond the VCA. A pseudocolor image of the standardized luminance is depicted in fig. 3 and indicates a successful formation of the desired distribution.

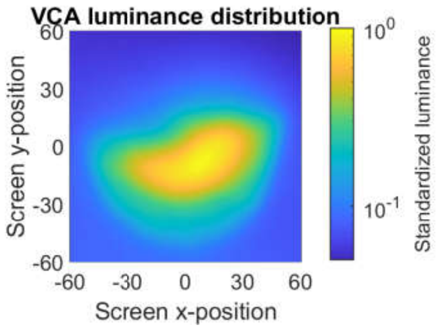

Fig. 3 *Pseudocolor image of the standardized luminance distribution generated by the VCA under whitelight-LED illumination. The screen is positioned in 545 mm distance to the VCA, which generates a small low-beam shaped light distribution.*

Figure 4 shows the standardized spectral radiance of the LED, the luminance distribution generated by the VCA and the laserwavelength used in the manufacturing process. As the VCA is produced in form of a reflection hologram, the wavelength selectivity is rather small.

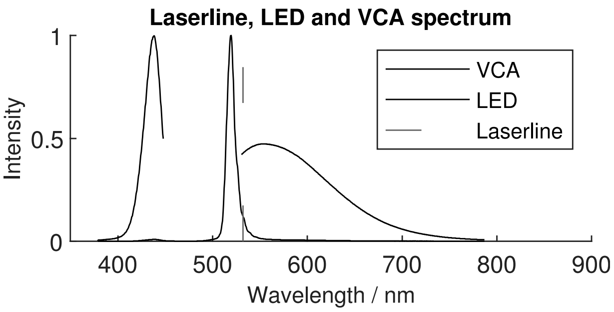

Fig. 4 *Standardized spectral radiance of the LED, the distribution generated by the VCA in fig. 3 and the laserline used for manufacturing.*

Due to shrinkage of the photopolymer, the peak wavelength of the VCA spectrum is slightly shifted compared to the laser wavelength.

4 Conclusion

In this article we showed a digital adaptation method, enabling volumeholographic cell-arrays to be used in combination with uncollimated LEDs at small illumination distances. Our approach uses conventional raytracing software to gather a suitable reference beam for each cell by calculating the arithmetic means of all lightrays incident on the specific cell. Yet it is important to be aware of some approximations:

- The direction components of the incoming rays in equation (1) are not weighted with the intensity of each ray. As the LED is used without any other optics or packaging, no absorption or reflection occurs, which would result in an intensity change. If one wishes to use additional primary optics, a weighted calculation of the arithmetic mean has to be implemented.
- Due to the composition of a whitelight LED, luminous intensity distributions are mostly given in a bluepart and a yellowpart of the LED spectrum. We used a laserwavelength of $\lambda_\mathrm{L} = 532$ nm for the VCA and therefore the yellowpart of the luminous intensity distribution.

References

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