Volumeholographic Grating Cell Arrays for Illumination Purposes

Markus Giehl*, Cornelius Neumann**
**L-LAB Research Institute for Automotive Lighting and Mechatronics, Lippstadt*
***Institute of Technology, Karlsruhe*
mailto:markus.giehl@l-lab.de

Due to wavelength and angular selectivity, computer generated volume holograms show high potential to substitute conventional optical elements. However, difficulties occur when using divergent and incoherent light sources for illumination. This paper presents a grating-cell approach to overcome those difficulties and allow for a fast computation of large scale optical elements.

1 Introduction

Holography has been succesfully industrialised for authenticity certificates or as an optical element e.g. in barcodescanners. Yet the usage of holograms as optical elements proves difficult when using light sources with characteristics that strongly differ from the wave during the manufacturing process, as reviewed in [1]. There are approaches [2], [3] to model the wavefront of an *LED* and take it into account during the calculation process, but as they use iterative Fourier-transform algorithms [4] to compute phase images, the quality of the target distribution is limited by the resolution of each hogel. Otherwise a single calculation of the complete matrix as a whole phase image would be necessary, which results in high demands for computation power, as the memory requirement scales by N^2 with image size N. In addition, as the phase image must be divided in hogels, high manufacturing tolerances are required. We present a Volumeholographic Cell Array (*VCA*) approach to overcome these difficulties.

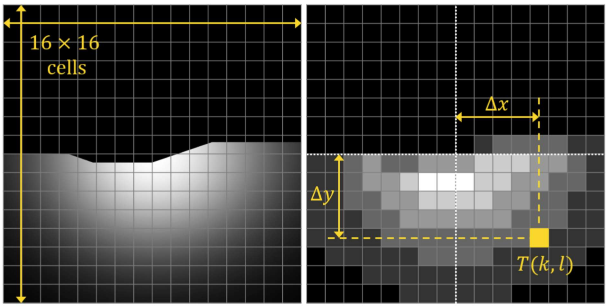
2 Calculation Method

Starting with a target intensity distribution in figure 1a, each cell is generated by simply calculating the phase information of a tilted square beam ϕ^G, using equation (1) and adding a lens function ϕ^L, described by equation (2), to focus oder widen the beam to its desired dimension in the target plane.

$$\phi^G_{ij}(k,l) = \frac{2\pi}{\lambda} \cdot \frac{x_{ij}(k,l)\Delta x_{mn} + y_{ij}(k,l)\Delta y_{mn}}{z} \qquad (1)$$

$$\phi^L_{ij}(k,l) = \frac{\pi}{\lambda} \cdot \frac{1}{f}\left(x^2_{ij}(k,l) + y^2_{ij}(k,l)\right) \qquad (2)$$

Δx_{mn} and Δy_{mn} are the lateral offsets of cell (m,n) in the target area T, as shown in figure 1b, while $x_{ij}(k,l)$ and $y_{ij}(k,l)$ denote the coordinates of pixel (i,j) of each hogel (k,l) in the source plane S. Additional parameters are the distance of the target plane to the holographic film z, design wavelength λ and focal length f. Figure 1b shows a target low resolution low-beam distribution, generated with 16×16 cells, which results in a total of 256 available pixelated light packages to form the desired image.



(a) (b)

Fig. 1 *(a) Example of a low beam distribution and (b) the low resolution target distribution, generated by combining pixelated light packages. The marked square denotes a single light pixel.*

The iterative algorithm to generate the *VCA* phase images is defined by the following steps:

1. Generate source intensity distribution image with cell array resolution and scale target intensity image to cell array resolution
2. Divide grayscaling of target image into $s = 2$ steps and create temporary field $I = S$
3. For each target cell that holds $T(k,l) > I(k,l)$ run through all source cells and if $S(m,n) > I(m,n) \wedge S(m,n) \geq T(m,n)$ then tag free source pixel as redistribute to pixel (k,l)
4. Do steps 2 and 3 and increase s until $T(k,l) \leq I(k,l)\ \forall\ k,l \in \mathbb{N}^+$ holds (all light packages are used)
5. Calculate tilt with (1) corresponding to redistribution coordinates in source and target plane and apply lens function using (2) to each cell to scale light packages

3 Experimental Results

The generated phase information is applied to a laser by a Spatial Light Modulator, overlayed with a plane wave and exposed at a reference angle of $50\,\mathrm{deg}$ and an object angle of $0\,\mathrm{deg}$ into a pho-

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topolymer. A $532\,\mathrm{nm}$ laser is used to write the hologram matrix. Figure 2 shows the spectral diffraction efficiency of the volume grating, calculated using [5] and the spectral intensity of the *LED* and the Laser light source, used to reconstruct the *VCA*.

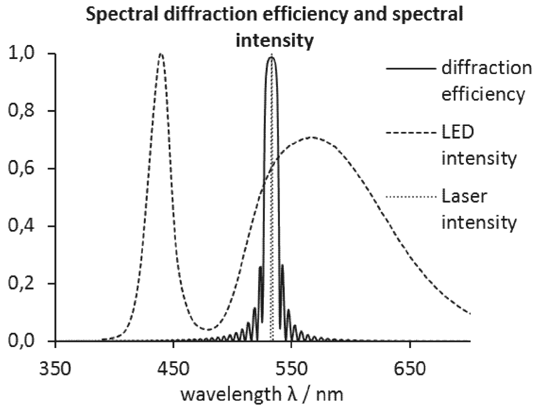
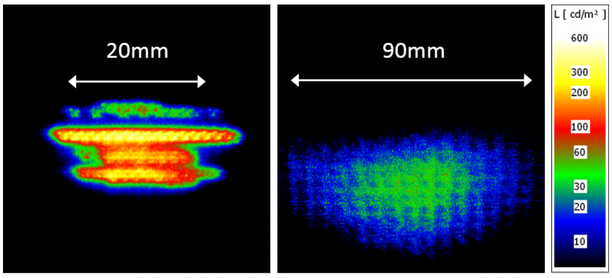


Fig. 2 *Spectral diffraction efficiency of a reflective volume grating and spectral intensity distribution of the used light sources.*

As the wavelength selectivity of reflection gratings is very high, only a small amount of the luminous flux will be used and therefore the luminance on the screen in case of *LED* illumination is very low.

The reconstructions of the *VCA* are shown in the case of laser illumination in figure 3. The luminance distribution in a distance of $150\,\mathrm{mm}$ is shown in figure 3a, where a reallocation of a squared shaped cell array to the desired low-beam distribution is still in progress and 3b shows the finalised redirection $950\,\mathrm{mm}$ beyond the holographic film.

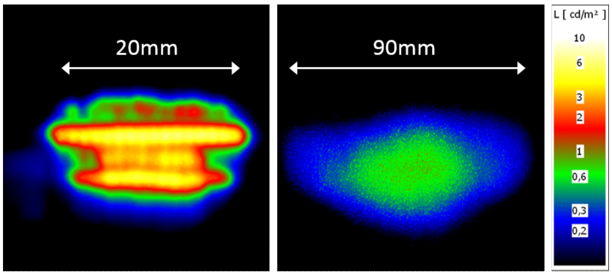


(a) (b)

Fig. 3 *False color luminance images of the* VCA *with Laser illumination in a distance of (a)* $150\,\mathrm{mm}$ *and (b)* $950\,\mathrm{mm}$

Quadratic structures, resulting from the low resolution target image and therefore the very principle of the grating cell array, are clearly visible in the generated light distribution. This may result in unwanted inhomogenities, which can be eliminated by adding an additional, randomly generated lensfunction to diffuse each square or by increasing the amount of cells.

But, as shown in figure 4 for the case of illumination with a collimated *LED*, the redistribution works as fine as for the case of laser illumination. In fact, the incoherency of the *LED* proves advantageous, as it strongly reduces the Fraunhofer artefacts in the far field of each cell, therefore making any additional efforts to reduce inhomogenities obsolete.



(a) (b)

Fig. 4 *False color luminance images of the* VCA *with* LED *illumination in a distance of (a)* $150\,\mathrm{mm}$ *and (b)* $950\,\mathrm{mm}$

4 Conclusion

The *VCA* approach to form light distributions for illumination applications shows high potential as it is robust to light source attributes, e.g. incoherency. As it is possible to calculate the phase information of each cell individually, a parallel and fast calculation of large cell arrays can be achieved. Additionally, the ability to manipulate each cell on its own, as there is no phase-dependency to each other, makes it possible to carry on with next steps, which will be the adaptation of the volume grating vector according to the ray data of the illumination source. This would allow the grating cell array to be used as the only optical element in a front lighting system without the necessity of collimation.

References

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