

Design and Simulation of Computer-generated Volume Holograms for Automotive Headlamps

Daniela Karthaus*, Oliver Sandfuchs**, Stefan Sinzinger***

*L-LAB – Research institute for automotive lighting and mechatronics, Lippstadt
Hamm-Lippstadt University of Applied Sciences, * Ilmenau University of Technology

<mailto:daniela.karthaus@l-lab.de>

The application of holograms as light shaping elements in automotive headlamps requires the adaption of the holographic information to the characteristics of the reconstruction light source. This paper shows first results regarding the adaption to different wavelengths for realizing a white light distribution by illuminating a hologram with a white light emitting light source.

1 Introduction

The aim of the project is the realization of a white light road illumination by using holograms supplementing or replacing optical components in automotive headlamp systems. Light sources typically used in headlamps, e.g. LEDs, are emitting divergent light with a broadband spectrum. This requires the adaption of holographic elements to these characteristics.

Therefore, holographic elements are realized as computer-generated matrix holograms (CGMH) that are composed of an amount of sub-holograms. Each sub-hologram is computationally optimized within a design process and exposed into a photopolymer with a SLM (spatial light modulator) based multi-step exposure process. The sub-holograms can be individually adapted to a specific wavelength, to the incident angle of the reconstruction light wave or to a specific local wavefront shape. In this paper the adaption to different wavelengths is presented and first experimental results for the verification of the design algorithms are discussed.

2 Theoretical Background

The recording wavelength and the reconstruction wavelength of a hologram are typically the same to get an unmodified reconstruction of the recorded information. If a different reconstruction wavelength is used, the resulting image is scaled and shifted according to the following equation [1]

$$n \cdot \sin(\theta_{in}) = n' \cdot \sin(\theta_{\lambda}) - \frac{\lambda}{g} \quad (1)$$

The diffraction angle θ_{λ} changes for the reconstruction of a hologram with fixed grating period g , when it is illuminated with different wavelengths λ at the same angle θ_{in} . Due to the exposure setup used in this project, the hologram is written with a wavelength of 532nm. As the reconstruction should be able with several wavelengths emitted

by a LED, the shift and scaling effects have to be compensated by the hologram. Therefore, the sub-holograms are optimized by taking sampling relations and properties of the Fourier transform into account.

To compensate the scaling effect [2], the relation between the size of the reconstruction Δx_{Rec} in a specific distance z and the sampling distance of the hologram dx_H are used. Δx_{Rec} is influenced by the wavelength and can be described by [3]

$$\Delta x_{Rec} = \frac{\lambda_{Ref} \cdot z}{dx_H} = \frac{\lambda_n \cdot z}{dx_H} \quad (2)$$

The size of the reconstructed images should be of the same size, using a reconstruction wavelength λ_n as well as using the reference wavelength λ_{Ref} . Therefore, the size of the design pattern has to be adapted depending on the reconstruction wavelength.

The modulation property of the Fourier transform is used to realize a desired shift f_{x0}, f_{y0} of the reconstruction $h(f_x, f_y)$ by multiplying the holographic information $H(x, y)$ with a phase term [4]

$$h(f_x - f_{x0}, f_y - f_{y0}) = \mathcal{F}\{H(x, y) \cdot e^{j2\pi(f_{x0}x + f_{y0}y)}\} \quad (3)$$

The spatial frequencies f_x, f_y, f_{x0}, f_{y0} can be calculated by

$$f = \frac{x}{\lambda_n \cdot z} \quad (4)$$

with x in spatial coordinates [3].

3 Verification of the Design Approach

To verify the design approach and the optimization steps, a specific test-setting is developed, shown in figure 1. The hologram is illuminated with three collimated diode lasers, emitting light with the wavelengths 450nm, 532nm and 635nm.

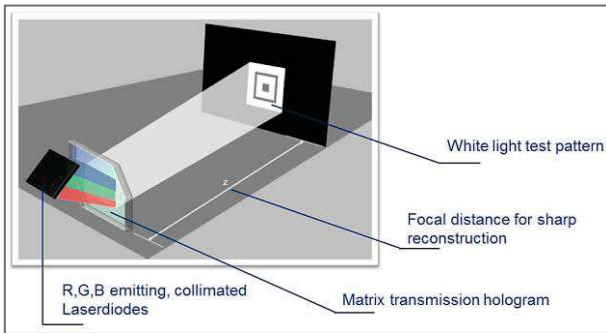


Figure 1: Schematic illustration of the test setting used to compare the design parameters and the experimental results.

The hologram is separated into three parts and the sub-holograms of each part are designed for one of the laser wavelengths. In addition, a lens function is added to every sub-hologram to get a focused image of the reconstruction in a distance of $z = 0.3\text{m}$ behind the hologram. Therefore, the reconstruction of each sub-hologram is shifted towards the optical axis, using equation 3. The lens function is necessary to prove the functionality of each sub-hologram. If the resulting focal distance is different to the specification, the sub-holograms are not modulating the wave correctly.

Within a first test series the hologram, optimized for 532nm, is illuminated with each diode laser and the lateral position, size and focal distance of the reconstructed image are determined. The results show the expected shift, scaling and blurring according to equation 1 as presented in figure 2a and figure 3.

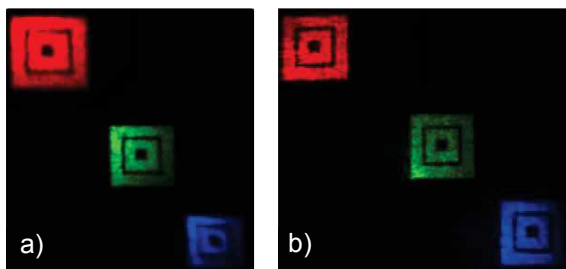


Figure 2: Reconstructed images for an unoptimized hologram (a) and optimized holograms (b), each illuminated with different wavelengths.

In comparison the reconstructions of the optimized holograms illuminated with the design wavelength show nearly the same size and the same focal distance as illustrated in figure 2b and figure 3. However, the lateral shift could not be finally compensated, due to limitations of the exposure process. While the realizable shift is about $\theta_\lambda = \pm 3.8^\circ$, a shift of $\theta_\lambda = -5.6^\circ$ for 635nm and of $\theta_\lambda = 4.6^\circ$ for 450nm is necessary. But the realization of smaller specified shifts leads to good results. It is as-

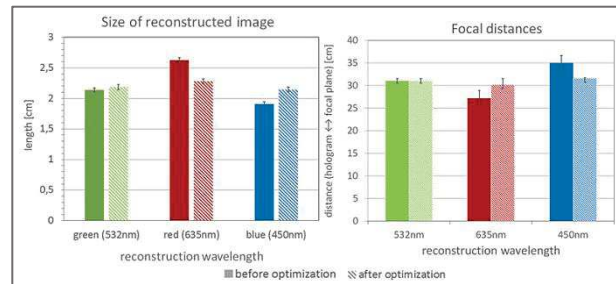


Figure 3: Changes of the reconstruction size and the focal length for unoptimized and optimized holograms, illuminated with different wavelengths.

sumed, that the optimization of the exposure setup solves this deficiency.

4 Summary and Outlook

The experimental results confirm the proposed design approach to compensate diffraction effects resulting from the illumination of a hologram with different wavelengths.

This confirmation is an important step towards the realization of white light distributions using a white light illuminated hologram. An optimization of a sub-hologram is possible for any wavelength in the visual spectrum emitted by a white light source without requiring a laser with the same wavelength for the exposure process.

However, there are still some challenges that have to be dissolved. One aspect is the simultaneous illumination of the sub-holograms with several wavelengths. It is assumed that an overlap of a major part of the emitted light to a white light distribution is possible. But the remaining light would be visible as color fringes. Of course these fringes cannot be eliminated completely, but they can be reduced with a sophisticated concept. Within future test series different concepts should be tested.

References

- [1] E. Hecht, *Optik*, 5. Auflage, (Oldenbourg Wissenschaftsverlag GmbH 2009)
- [2] J. Zhao, H. Jiang, J. Di, "Recording and reconstruction of a color holographic image by using digital lensless Fouriertransform holography", *Optics Express* Vol. 16, No. 4, 2514-2519 (2008)
- [3] D. Voelz, *Computational Photonics – a MATLAB® Tutorial* (SPIE Press, 2011), Chap. 5
- [4] B. E. A. Saleh and M. C. Teich, *Fundamentals of Photonics* (John Wiley & Sons, Inc., 2007), Chap. A.1.1