Iterative scalar algorithm for the rapid design of wide-angle diffraction Fourier elements

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Summary

We demonstrate that non-paraxial Fourier elements can be designed by an iterative Fourier transform algorithm with the help of a simple projection step. The element designed by this model shows better reconstruction in both spots position and power distribution than the one of the paraxial design and very close to the desired pattern.

Introduction

Recent development in fabrication technology has enabled manufacturing of non-paraxial Diffractive Optical Elements (DOEs), which could have higher efficiency, better uniformity and an ever broadening field of applications. However, the scalar paraxial theory fails to model these DOEs correctly, leading to the need for wide-angle diffraction modeling and design. More rigorous design algorithms have been developed [1], but their applications are often limited due to the extensive calculation required. It has been reported that the diffraction pattern on a hemisphere in the far-field can be calculated accurately using a simple Fourier transform [2].

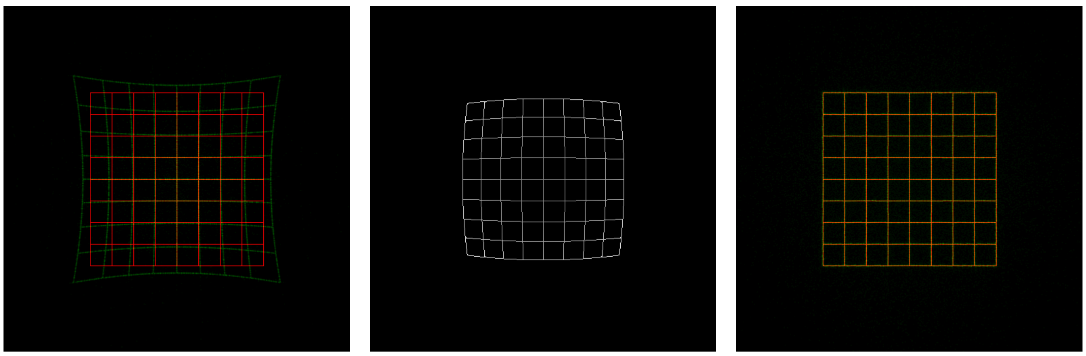
We aim to reduce computational complexity of the design model by developing a rapid algorithm using a projection of a desired pattern from the output plane to the hemisphere and iterative Fourier transform between the hemisphere and the DOE plane. The design can be used for non-paraxial Fourier elements which have many applications in practice, e.g. beam splitters, beam shapers, where the propagation distance is often much larger than the DOEs size [1]. The reconstruction pattern of the DOE designed by our model shows better distribution in both position and intensity than the one designed by a standard multi-stage iterative Fourier transform algorithm (IFTA) [3] and very close to the desired pattern.

Discussion

For non-paraxial scalar diffraction, a Fourier transform can be used to propagate the diffracted field to a hemisphere in the far-field [2], but not directly to the observation plane as in the scalar paraxial theory. The diffraction pattern on the output plane can be obtained by using a simple spherical wave projection from the hemisphere, resulting in:

$$U(\alpha,\beta;z)=\frac{\gamma^2\exp(ikz/\gamma)}{i\lambda z}FT\{U(x_1,y_1;0)\}$$

where α,β,γ are the direction cosines of the angles between the diffracted wave and the spatial coordinates. A re-sampling step is then required to interpolate the field in the output plane from angular $U(\alpha,\beta;z)$ to spatial coordinates $U(x_2,y_2;z)$ on a uniform sampling grid. For paraxial diffraction, the hemisphere and the output plane overlap approximately and this projection step can be neglected. However, the projection is more important for wide-angle diffraction, as shown in Fig. 1(a) where the reconstruction pattern is distorted compared to the desired pattern, which is a square grid with the diffraction angle of about 30^o at the corners. The element is designed using a paraxial IFTA with a smallest pixel size of 1μm and operating at the wavelength of 1.55μm, while the reconstruction pattern is obtained using the rigorous Rayleigh-Sommerfeld (RS) diffraction formula [4]. The other distortion is in intensity distribution, where the higher the diffraction angle, the less the spots power. This is due to the power estimation in the paraxial design ($P \propto |U|^2$) without taking into account the non-paraxial angle between the direction of diffracted beam with the normal of the observation plane ($P \propto |U|^2\gamma$).



(a) (b) (c)

Fig. 1. (a) Result of the traditional IFTA. The red pattern is the desired output, whereas the green pattern is the reconstruction of the designed DOE. The yellow regions are where they overlap. (b) Projection of the desired pattern from the observation plane to the hemisphere. (c) Superposition of the desired pattern and the reconstruction of the DOE designed by our proposed algorithm

To solve these problems for the design of non-paraxial Fourier elements, the desired pattern is back projected from the observation plane to the hemisphere before using iterative Fourier transform between the DOE plane and the hemisphere. Fig. 1(b) illustrates the projected pattern in angular coordinates on the hemisphere, where the spot intensity has been corrected according to the diffraction angle. A nearest neighbour interpolation is used for mapping the field from spatial to angular coordinates. The element is then designed by using the standard multi-stage IFTA having this image as the output pattern. Fig. 1(c) demonstrates the superposition of the desired pattern and the RS reconstruction on the observation plane of our designed DOE, which shows almost the same spatial and intensity distribution.

Conclusion

We present an efficient scalar model using the traditional iterative Fourier transform with the help of a spherical projection to design non-paraxial Fourier elements, while the calculation complexity is much simpler than the available rigorous models. The simulated results show that the DOE designed by this algorithm performs better reconstruction and uniformity than the one of the paraxial IFTA design and very close to the desired pattern. The DOEs are being fabricated for experimental verification.

References

[1] B.C. Kress, and P. Meyrueis, *Applied Digital Optics*, John Wiley & Sons, 2009.
[2] J.E. Harvey, D. Bogunovic, and A. Krywonos, *Applied Optics*, vol. 42, p. 1167, 2003.
[3] F. Wyrowski, *Applied Optics*, vol. 28, p. 3864, 1989.
[4] J.W. Goodman, *Introduction to Fourier Optics*, McGraw-Hill, 1996.