Improvement of free-space optical interconnection efficiency by using circular aperture CGH

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Abstract: We improve the free-space optical interconnection efficiency by using circular aperture computer-generated hologram (CGH). In free-space optical interconnection system using CGH, the single CGH is composed of sub-CGHs, which can change the direction of input beams to desired output positions, by Fourier transform. Each sub-CGH is rectangular shape, so the input beams through each sub-CGH are transformed to sinc functions in output plane. The side lobes of each sinc function are superimposed in output plane and they result in detection error in output plane, so the detection efficiency is low. We use the circular shaped sub-CGHs in order to reduce the side lobe value in output plane instead of rectangular shaped sub-CGHs. The each input beam is transformed to first-order Bessel functions through circular shaped sub-CGHs in output plane. The side lobes of first-order Bessel functions are low values compared with side lobes of sinc function, so we can improve the detection efficiency in output plane. We use binary phase modulated CGH, and confirm this improvement results by simulation.

1. Introduction

The optical interconnection has been noticed bcause of many advantages such as high-speed transmission, large spatial bandwidth, and low cross talk. Among the many techniques[1-2] used for optical interconnections, free-space optical interconnection is one of the most suitable methods to promise the large spatial bandwidth and high-speed. Free-space optical interconnection can be implemented by using the optical elements. The computer-generated hologram (CGH) is attractive optical elements that provide large spatial bandwidth, easy and low-cost structure. Most of all, the CGH patterns are programmable and reconfigurable, so they are normally used to define the free-space interconnection patterns[3-4]. There are N×N sub-CGH patterns in single CGH pattern to implement N×N channel interconnections in free-space interconnection system. The each sub-CGH pattern plays a role of the phase-shift function and it changes the direction of input beams to the desired output positions by Fourier transform. In the case of interconnecting a number of inputs, the superimposed patterns in output plane result in detection error and it reduce the detection efficiency.

In this paper, we propose the circular shaped sub-CGH pattern to enhance the detection efficiency in output plane. Normally single CGH pattern consist of some rectangular shaped sub-CGH patterns. Through these sub-CGH patterns, the input beams transform to sinc function in output plane. The superimposed side lobes of sinc functions result in cross talk in output plane. Circular shaped sub-CGH patterns make the input beams transform to first-order Bessel functions in output plane. The side lobes of first-order Bessel function is much smaller than the side lobes of sinc function, so we can improve the detection efficiency by using the circular shaped sub-CGH patterns. We use the binary-phase CGH pattern that has 0 or π state in simulation because it is highly efficient and can create arbitrary interconnection pattern.

2. Space -variant Optical interconnection by CGH

Each Input beam transmits the each sub-CGH and it changes the direction of each input beam to desired output position. This interconnection using sub-CGH is called space-variant interconnection[5], as shown in Fig. 1.

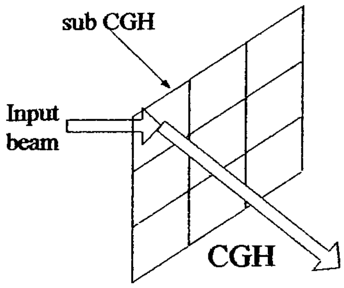

Fig. 1. Space-variant optical interconnection by CGH.

The single CGH is composed of N×N sub-CGHs, which are the rectangular shapes, so the sub-CGHs transform the input beams to sinc functions in output plane by Fourier transform. The side-lobes of sinc functions reduce the detection efficiency in output plane.

3. Comparison rectangular sub-CGH with circular sub-CGH

The Fig. 2 shows the sub-CGHs which are rectangular and circular shapes.

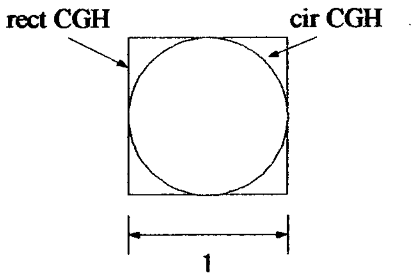

Fig. 2. Rectangular and circular sub-CGH

If we assume the diameter of circle and the width of rectangle is 1, the Fourier transform of rect(x,y) in Fig. 2. is

$$F\{\text{rect}(x,y)\} = \frac{\sin\{(\pi f_x, \pi f_y)\}}{(\pi f_x, \pi f_y)}$$

And the first-order peak value is given by

$$\frac{\sin(\pi \times 1.5)}{\pi \times 1.5} \cong -0.212, \text{ when } f_x = 0.5.$$

So intensity is $(-0.212)^2 = 0.045$.

The Fourier transform of cir(x/w) is

$$F\{\text{cir}(x/w)\} = w \times \frac{J_1(\pi w \rho)}{\rho}, \text{ where } \rho = \sqrt{f_x^2 + f_y^2}.$$

And the first-order peak value is given by

$$0.5 \times \frac{J_1(\pi \times 1.635)}{1.635} \cong -0.101, \text{ when } \rho = 1.635.$$

So, the intensity is $(-0.101)^2 = 0.010$.

4. Simulation

We can expect low effect of side-lobes when we use circular shaped sub-CGH. We simulate 4×4 sub-CGH pattern.

Fig. 3 and Fig. 4 show the rectangular and circular shaped 4×4 sub-CGH patterns.

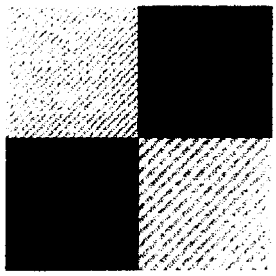

Fig. 3. 4×4 rectangular sub-CGH pattern.

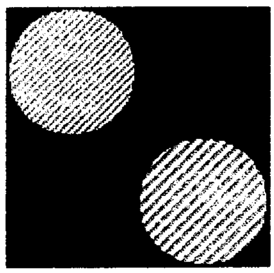

Fig. 4. 4×4 Circular sub-CGH pattern.

We use the binary phase hologram to change the directions of input beams. The gray represents π phase and white represent 0 phase. Fig. 5 and Fig. 6 show the output patterns in detection area by sub-CGHs.

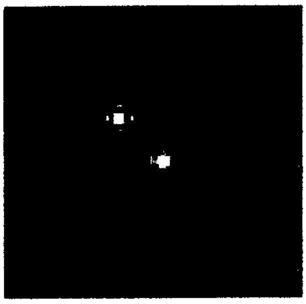

Fig. 5. Output pattern by rectangular sub-CGH

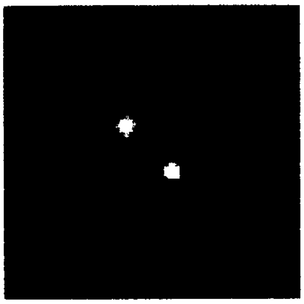

Fig. 6. Output pattern by circular CGH

We restrict the detection area because the binary-phase hologram produces the symmetric patterns in output plane. The superimposed side-lobe is shown by Fig. 7 and Fig. 8.

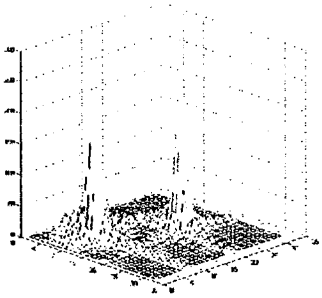

Fig. 7. The superimposed side-lobes of Fig. 5

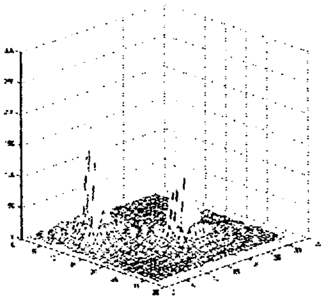

Fig. 8. The superimposed side-lobes of Fig. 6

Fig.8 has much smaller side-lobes than Fig.7 and it represents low cross talk in circular sub-CGH.

5. Conclusion

In this paper, we propose circular aperture CGH for free-space optical interconnection. We show that the proposed circular sub-CGHs result in low cross talk compared with rectangular sub-CGHs, so it can improve the detection efficiency in output plane. We confirm this result by simulation and also can confirm it by optical experiment.

References

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