홀로그래픽 정보저장장치에서 디지털 이미지 마스크를 이용한 실시간 광량 제어 알고리즘

Real Time Light Intensity Control Algorithm Using Digital Image Mask for the Holographic Data Storage System

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Abstract

Holographic data storage system(HDSS) has many noise sources – crosstalk, scattering and inter pixel interference, etc. Generally the intensity of a light generated from the laser source has Gaussian distribution and this ununiformity of light also can make the data page to have a low SNR. A beam apodizer is used to make the laser as a flat-top beam but the intensity distribution is not strictly uniform. The intensity of light can be controlled using image mask. In this paper the intensity distribution of light used for HDSS is controlled by a digital image mask. The digital image mask is changed arbitrarily in real-time with suggested algorithm for the HDSS.

Key Words : Holographic data storage, digital image mask, noise reduction

1. Introduction

The optical system using light source like a laser must have the intrinsic features oriented from the original nature of the light – dispersion, polarization and diffraction, etc. The holographic data storage system (HDSS) stores user data by the interference pattern of two beams in the holographic media and retrieves the data by receiving diffracted light from the interference pattern[1][2][3][4][5][6]. These natures of light make HDSS to be able to store data but can be a noise source by changing intensity of the light used for carrying the data signal.

HDSS has many noise sources – crosstalk, scattering and inter pixel interference, etc. Generally the intensity of a light generated from the laser source has Gaussian distribution. In addition, intensity of the light can be distorted by a dust, diffraction or another light shining through. The uniformity of light intensity in the signal arm can make the data page to have a low SNR. A beam apodizer can be used to make the signal beam as a flat-top beam but the intensity distribution is not strictly uniform. If an image mask is put in front of SLM in the signal arm, the intensity of signal beam can be controlled using the image mask[7]. In this paper the intensity distribution of light used for HDSS is controlled by a digital image mask. The digital image mask is changed arbitrarily for the uniform intensity distribution of the light.

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2. Point Spread Function

The spread of radiant flux is described mathematically by the function $\Pi(y,z;Y,Z)$, such that the flux density arriving at the image point from $dydz$ is [8]

$$dI_i(Y,Z) = \Pi(y,z;Y,Z)I_0(y,z)dydz \qquad (1)$$

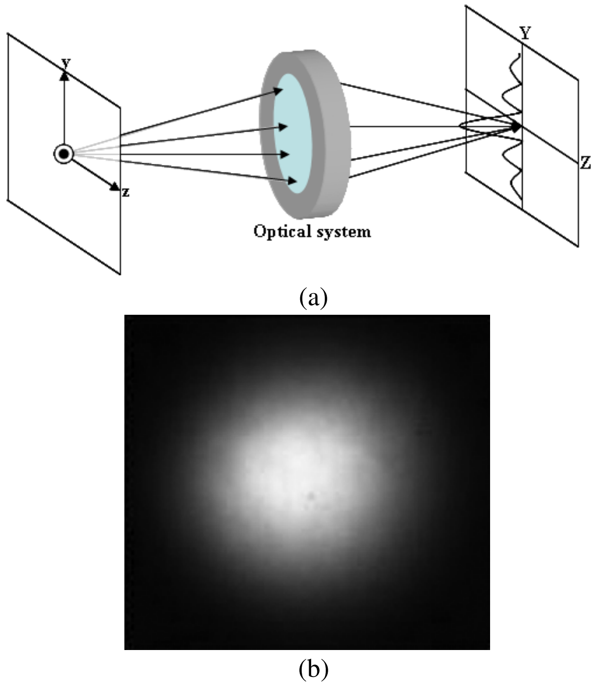


Fig. 1 The point-spread function and Gaussian distribution

This is the patch of light in the image plane at (Y, Z), and $\Pi(y, z; Y, Z)$ is known as the point-spread function. The point-spread function has a functional form identical to that of the image generated by a δ-pulse input. It's the impulse response of the system, whether the optical system is optically perfect or not. In well-corrected system Π, apart from a multiplicative constant, is the Airy irradiance distribution function centered on the Gaussian image point.

In HDSS, the laser can be regarded as a point source (δ-pulse input). If we consider SLM as the image plane, the irradiance of signal beam at the image plane has the Gaussian distribution because the laser can be thought as a point source. Figure 1(a) shows the point-spread function and (b) is the intensity distribution measured by a CCD camera.

3. Light Intensity Control

In order to retrieve a data page with good SNR it is necessary to make the intensity distribution of the signal beam uniform in front of SLM. The image mask can be a key component for a uniform intensity distribution. The digital image mask controlled by a computer is set in front of data image to be recorded like figure 2[9].

The basic image mask is calculated to reduce the beam intensity of brighter area to be the desired intensity at image plane. If the input beam profile is the Gaussian distribution, the image of digital mask is obtained as figure 3(a) and intensity distribution through the image mask is measured as figure 3(b) when beam profile of figure 1(b) is inputted and desired intensity is set to 100 of 256 level gray scale. Figure 3(c) is intensities of pixels at the center line of each figure. Concept of the image mask is presented in the figure 3(c). As shown in the figure, at the specific area around center of the beam the intensity becomes uniform equal to 100 set value by the digital image mask.

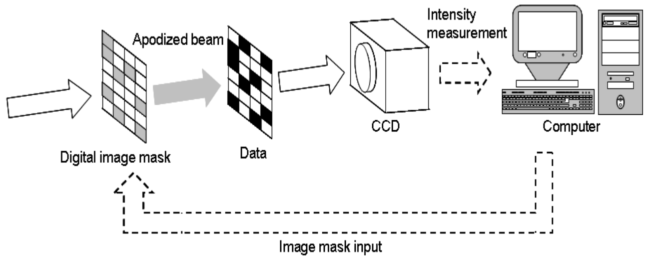


Fig. 2 Schematic diagram of light intensity control with digital image mask

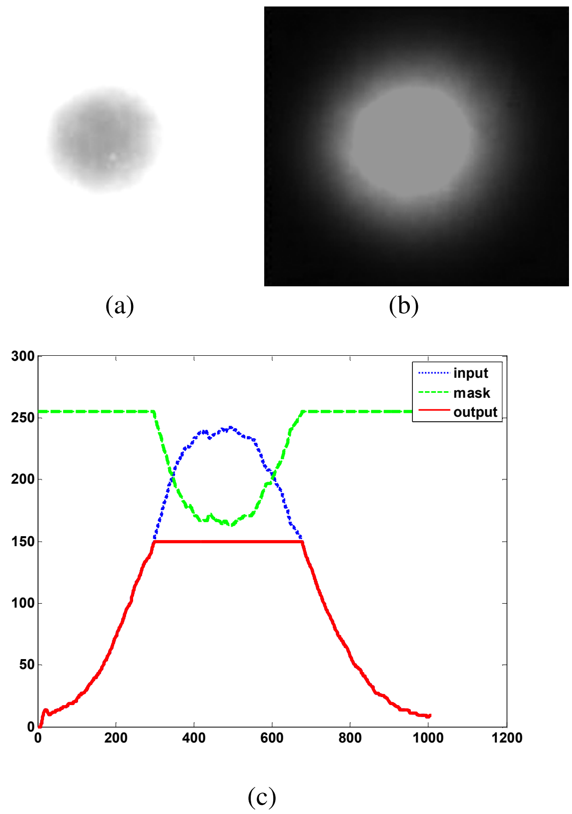


Fig. 3 Image of the mask and intensity change after image mask

4. Inter Pixel Interference Noise

By the Fraunhofer diffraction theory, the beam from the laser source emits as a plane wave. However after crossing the aperture – SLM, the beam propagates as a spherical wave from many point sources and diffracts. The on-pixels of SLM allow the beam to pass through, but the off-pixels do not. So an on-pixel acts like as an aperture, and the beam through the on-pixel of SLM will affect to surrounding pixels by 2-dimensional Fourier Transform[2]. This effect acts as one of main noises, and is called "Inter Pixel Interference" noise.

Inter Pixel Interference (IPI) degrades the performance of the channel, and it tends to occur when an off-pixel is surrounded by on-pixels or vice versa. Where there are many on-pixels in comparison, errors from IPI noise will appear relatively high than other area of data page. Therefore if we find the cluster of on-pixels and reduce the intensities of the on-pixels, the possibility of error by IPI noise will decrease than before. And about the whole data page because the intensity of laser of brighter area will be decreased, uniform intensity profile will be obtained.

The IPI noise from 2-dimensional Fourier transform is shown in figure 3. And to make simulations with IPI noise, it is necessary to set the numerical values of IPI noise. To obtain the numerical values of IPI noise, two-dimensional Fast Fourier Transform (function 'fft2' of MATLAB) is used[10][11]. From the result of MATLAB, the artificial IPI noise similar to the real IPI noise is made. Figure 4 describes the effect of one on-pixel to surrounding pixels with normalized intensity value 1. As shown in figure 4, the effect exists mainly to horizontal and vertical direction (there is no effect to the diagonal direction in artificial IPI noise). To just neighboring pixels value of the effect of IPI noise is set to 0.135 and to the next the value is set to 0.075 when the maximum intensity value is normalized to 1[12]. With the numerical values in figure 4(b) a data page with IPI noise can be made artificially. Figure 4(c) is a data page with artificial IPI noise. When we reconstruct a corresponding data page with the data of figure 4(c) using threshold method then 1803 error pixels are found with threshold value of 0.5.

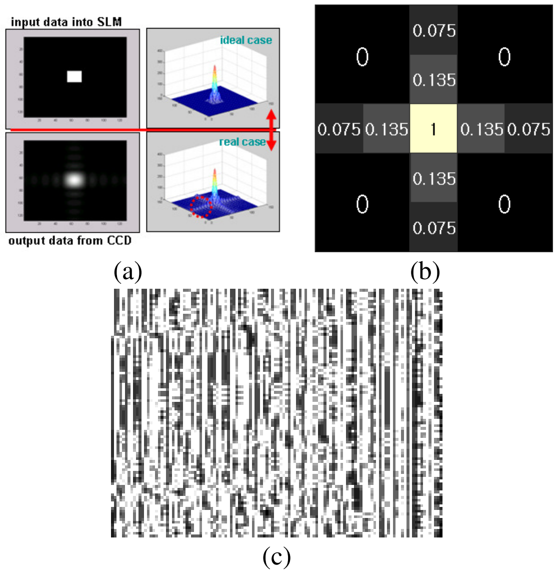


Fig. 4 Inter pixel interference noise and its numerical values

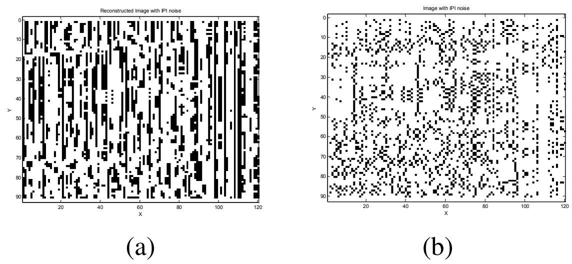
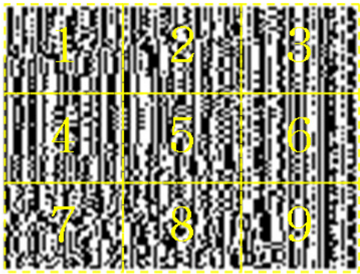


Fig.5 Reconstructed data page with IPI noise and error pixels

5. Design of Image Mask against IPI Noise

The digital image mask can be used to reduce number of error pixels from IPI noise. If we can control each pixel of image mask, the best performance can be shown with the intensity control system. However it would consume huge time for calculation to control each pixel of the image mask, it may not be suitable for data storage system. Considering about both of the performance and the calculation time, the image mask is divided into 9 partitions. Intensity of the signal beam passes through each partition is controlled individually by the image mask. Figure 6 shows the control scheme of digital image mask with 9 partitions and an example of the generated image mask.



(a)

(b)

Fig. 6 Control scheme of image mask with 9 partitions

Intensity of the signal beam will be reduced differently by transmittances of 9 partitions of digital image mask. To calculate the optimal transmittance of each partition the back propagation algorithm of neural network is used.

5.1 Neural Network

A neural network is a massively parallel distributed processor that has a natural propensity for storing experiential knowledge and making it available for use[13]. It resembles the brain in two respects :

Knowledge is acquired by the network through a learning process.

Interneuron connection strengths known as synaptic weights are used to store the knowledge.

The procedure used to perform the learning process is called a learning algorithm, the function of which is to modify the synaptic weights of the network in an orderly fashion so as to attain a desired design objective.

The modification of synaptic weights provides the traditional method for the design of neural networks. Such an approach is the closest to linear adaptive filter theory, which is already well established and successfully applied in such diverse fields as communications, control, radar, sonar, seismology, and biomedical engineering. However, it is also possible for a neural network to modify its own topology, which is motivated by the fact that neurons in the human brain can die and that new synaptic connections can grow.By the Fraunhofer diffraction theory, the beam from the laser source emits as a plane wave. However after crossing the aperture – SLM, the beam propagate

5.2 Back Propagation Algorithm

The back propagation algorithm[5] makes the network to learn until the output vector being resembled with the input vector or classified into proper input vector. To minimize mean square error of the network control weights and biases using back propagation rules. This procedure changes weights and biases for the direction of reducing the error as fast as possible. The variations of weights and biases are proportional to the effects of the elements about mean square error of the network.

It often happens to get not the global minimum but the local minimum when using back propagation learning. For that case to get the global minimum it is necessary to construct the network with more neurons and layers, then the problem becomes complex. Sometimes using another initial condition can solve the problem.

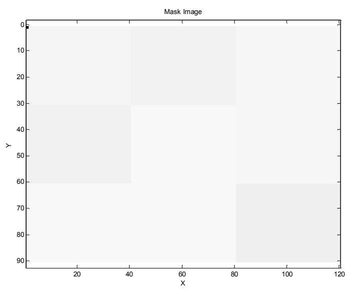
6. Results of Simulations

The optimal values of transmittance of 9 partitions are obtained using back propagation algorithm in figure 7(a). Figure 7(b) is the image of digital image mask made with values of figure 7(a).

Using the digital mask number of error pixels is reduced to 33 with a threshold method of the same threshold value with figure 5. Figure 8(a) shows the decrease of number of error pixels as iteration epoch and figure 8(b) shows error pixels found from reconstructed data page.

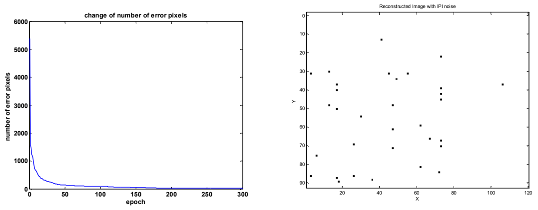
0.5409	0.5527	0.5330
0.5548	0.5289	0.5367
0.5293	0.5308	0.5616

(a)



(b)

Fig. 7 The digital image mask with optimal transmittances



(a) (b)

Fig. 8 Error pixels of reconstructed data page using the optimal image mask

7. Conclusions

In this paper, a new concept for improvement of performance of HDS is suggested. The light intensity control using a digital image mask can improve the quality of the signal beam before SLM so that a data page can be recorded with a signal beam of uniform intensity distribution. In addition, the signal beam after passing through the image mask has an intensity distribution changed arbitrarily by the image mask. Therefore we can change the intensity of the signal beam in order to eliminate the effect of IPI noise. Considering both of the performance and computational time, the digital image mask is divided into 9 partitions and transmittance of each partition is calculated using back propagation algorithm of neural network. The number of error pixels is reduced from 1803 to 33 within 200 iterations.

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참고문헌

[1] Hans J. Coufal, Demetri Psaltis and Glen T.Sincerbox, 2000, *Holographic Data Storage*, Springer, New York, USA.

[2] K. Curtis, A. Pu and D. Psaltis, 1994, "Method for Holographic Storage using Peristrophic Multiplexing", Opt. Lett. vol. 19, pp. 993-994.

[3] S.-K. Kim, K.-T. Kim and E. S. Kim, 1999, "Non-Mechanical Angular Multiplexed Holographic Memory System using Moving Window on Liquid Crystal Display", Jpn. J. Appl. Phys. vol. 38, pp. 38–40.

[4] J.-S. Jang, D.-H Shin and Y.-S Park., 2000, "Holographic data storage by combined use of Peristrophic, Angular and Spatial Multiplexing", Opt. Eng. , vol. 39, pp. 2975–2980.

[5] Li H-YS, Psaltis D, 1994, "Three dimensional holographic disks", Applied Optilc, Vol 33, No 17, pp.3764-3774.

[6] Ken Anderson, Kevin Curtis, 2004, "Polytopic multiplexing", Optics Letters, vol .29, Issue. 12, pp. 1402-1404.

[7] J. M. Gonzalez-Leal, 2004, "Automated system for the study of volume holographic recording", AIP, vol .75, no. 9, pp. 2899-2902.

[8] Eugene Hecht, 2002, *OPTICS* 4th edition, Addison Wesley, San Francisco, USA.

[9] Normal S. Nise, 2000, *Control Systems Engineering 3rd ed.*, Wiley, USA.

[10] Bahram Shahian, Michael Hassul, 1993, *Control Systems Design Using MATLAB*, Prentice Hall International Edition, USA.

[11] Rafael C. Gonzalez and Richard E. Woods, 2002, *Digital Image Processing*, Prentice Hall, New Jersey.

[12] Sang-Hoon Kim, Jang Hyun Kim, Hyunseok Yang, and Young-Pil Park, 2005, "Design Error Corrector of Binary Data in Holographic Data Storage System Using Subclustering", Proceeding of ISPS'05.

[13] Simon Haykin, *Neural Network.*