근접 픽셀 에러 감소를 위한 홀로그래픽 데이터 스토리지 시스템의 퍼지 규칙 생성

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Design error corrector of binary data in holographic data storage system using fuzzy rules

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Key Words : Fuzzy rules, Holographic data storage system, Inter pixel interference, Bit error, Subtractive clustering

ABSTRACT

Data storage related with writing and retrieving requires high storage capacity, fast transfer rate and less access time. Today any data storage system cannot satisfy these conditions, however holographic data storage system can perform faster data transfer rate because it is a page oriented memory system using volume hologram in writing and retrieving data. System can be constructed without mechanical actuating part therefore fast data transfer rate and high storage capacity about $1Tb/cm^3$ can be realized. In this paper, to reduce errors of binary data stored in holographic data storage system, a new method for bit error reduction is suggested. First, find cluster centers using subtractive clustering algorithm then reduce intensities of pixels around cluster centers and fuzzy rules. Therefore, By using this error reduction method following results are obtained ; the effect of Inter Pixel Interference noise is decreased and the intensity profile of data page becomes uniform therefore the better data storage system can be constructed.

1. INTRODUCTION

Holographic Data Storage System[1][2], one of the next generation data storage principle, is a 2-dimensional page oriented memory using volume hologram in writing and retrieving process. In the HDS system, data management procedure is performed in parallel so fast data transfer rate can be realized. And the system stores data in binary form (0 or 1), so that computers can use the digital data directly. In writing procedure, Laser of specific wavelength passes through a Spatial Light Modulator (SLM) to make 2-dimensional data page. A digital data 0 makes image of a black pixel (off-pixel) by blocking the light on SLM and digital data 1 is imaged as a white pixel (on-pixel) on CCD camera.Diffraction, the nature of light, makes the laser which passes through an on-pixel surrounded by off-pixels on SLM to affect surrounding pixels by 2-dimensional Fourier Transform of a plane wave and when retrieving process the effects to surrounding pixels of an on-pixel are photographed by CCD camera and cause errors to binary data.

In this paper, we analyze the effect of an on-pixel (digital data 1) to surrounding off-pixels (digital data 0) and suggest a new method for reducing errors of binary data using subtractive clustering methods[3][4][5]. The error reduction algorithm is that ; find centers of on-pixel group and reduce the effect of on-pixels. To find centers of on-pixel groups, Fuzzy system by subtractive clustering algorithms and DNA coding method are used.

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Fig. 1 is the HDS system experiment test bed.

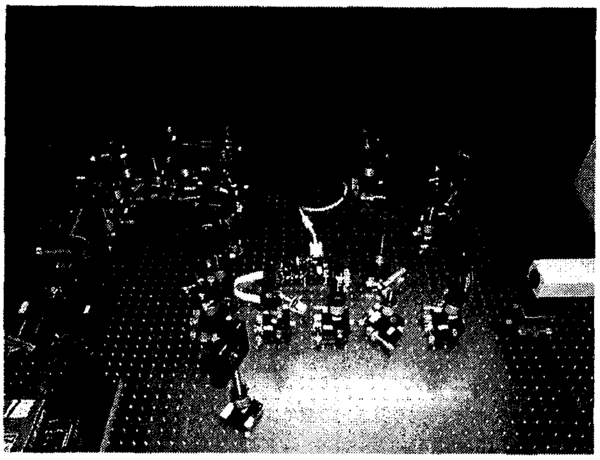


Figure 1: HDS system experiment test bed

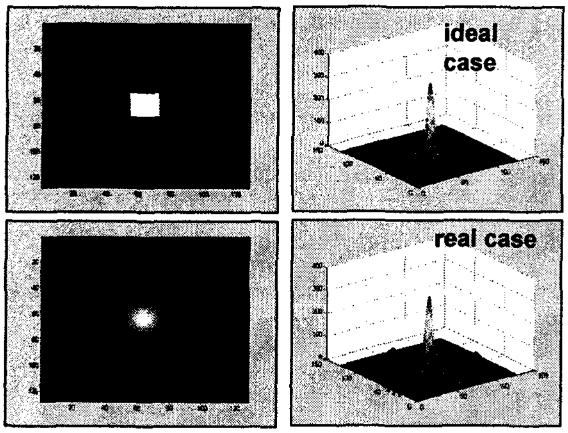


Figure 2: Beam intensity profile after passing through a rectangular aperture

2. IPI Noise and subtractive clustering algorithm

IPI 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 Fig. 2.

3. Fuzzy rules generated from clustering

Clustering Algorithm

Subtractive clustering[3][4] can identify fuzzy system models according to determining cluster centers from numerical input-output data. The number of cluster centers corresponds to the number of fuzzy rules. If we consider the Sugeno-type fuzzy model, the parameters are also determined from the clustering algorithm. The clustering algorithm calculates the potential values P_i from N normalized data obtained from the input-output product-space.

Yet , $i = 1, \cdots, N$ and γ_a is a positive constant to set data far apart from a cluster center not to have influence on the potential value. The first cluster center x_1^* corresponds to the largest potential value P_i^* . The second cluster center is calculated after removing the effect of the first cluster center. Eq. 2 shows how to remove the effect of the first cluster center. The second cluster center x_2^* corresponds to the largest potential value of P_i'.

$$P_i' = P_i - P_i^* \exp(-\beta \|x_i - x_k\|^2), \quad \beta = 4/\gamma_a^2 \quad (2)$$

Positive constant γ_b prevents cluster centers to assemble to close. This process repeats until potential values reach a fixed limit $(\varepsilon, \bar{\varepsilon})$.

Cluster centers $\{x_1^*, x_2^*, \cdots, x_M^*\}$ determine M fuzzy rules. They also determine the center position of input membership functions. Widths of membership functions are fixed according to experience. The parameters $\alpha_{i0}, \alpha_{i1}, \cdots, \alpha_{in}$ can be optimized by linear least squares estimation[5] or adaptive training algorithms.

DNA Coding Method

In this section, we briefly review the basic mechanism of DNA coding method and present DNA coding method for identification of parameter for fuzzy system.[8]

The biological DNA consists of nucleotides which have four bases, Adenine(A), Guanine(G), Cytosine(C), Thymine(T) [8]. The biological DNA have mRNA. and mRNA have the unused parts. Then the unused parts are cut out. This poeration is a splicing. After this splicing occurred, the mRNA is completed. Three successive bases called codons are allocated sequentially in the mRNA. These codons are the codes for amino acids. 64 kinds of codons correspond to 20 kinds of amino acids. The details of translation into amino acid from codons are omitted here. Amino acid makes proteins, and The proteins make up cells.

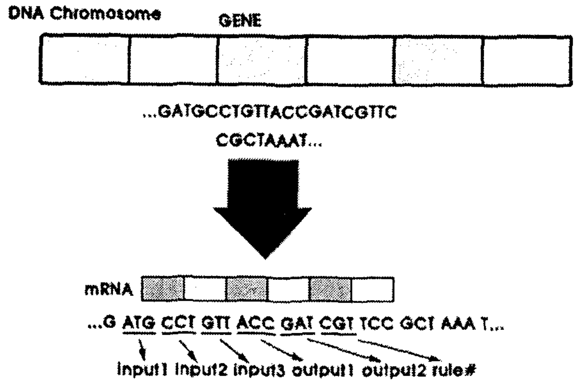


Figure 3: Biological DNA coding method

In this method, a codon is regarded as a gene value in conventional GAs. For example, a codon (A,G,C) may represent real value 24. Figure 4 shows an example of the DNA chromosome and its translation

Fig. 3 shows the diagram of DNA coding method The GA usually used a coding method specifically devised for each problem and it had no redundant parts. In this paper, A, G, C and T are represented by integer number 1, 2, 3, and 4 for simplicity. In the DNA coding method, the overlapping of genes is a crucial feature, which makes DNA coding more effective. Fig. 4 shows the overlapping of genes. As shown in the Fig. 4, many genes can be constructed from a single DNA. For this reason, One may ask how to select end-codon for a start-codon. This problem can solved by first-come-first-serve rule.

In DNA coding method the crossover is simply replaced the parts of DNA on the crossover points as in conventional GAs and the mutation is change the a randomly selected base to its complement. Fig. 5 shows an example of crossover and Fig. 6 shows an example of mutation

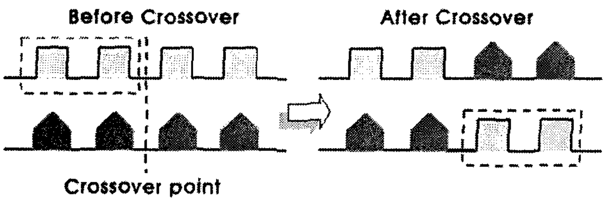


Figure 5: Crossover of DNA coding method

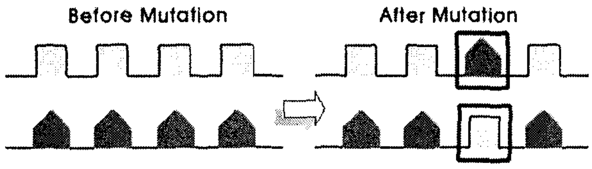


Figure 6: Mutation of DNA coding method

The next step is to construct the proper structure of DNA code. In this paper we use n input and n output fuzzy inference system. We use DNA coding method about optimize cluster radius size of Subtractive clustering parameter.

Generating fuzzy rules for error corrector of IPI Noise Sugeno fuzzy system model[5] is used to represent effects of Inter Pixel Interference for holographic data storage sytem. The MISO type fuzzy rules are of the form given in Eq. 3.

$$IF\ x_1\ is\ A_{i1}\ and\ x_2\ is\ A_{i2}\ and\ \cdots\ x_n\ is\ A_{in} \quad THEN\ y_1 = a_{0i} + a_{1i}x_1 + \cdots + a_{ni}x_i \tag{3}$$

A_{ij} is Gaussian membership functions for input fuzzy variables, coefficients $a_{0i}, a_{1i}, \cdots, a_{ni}$ determine the output of the fuzzy system. Fuzzy modeling process based on the clustering of input-output data determines the centers of the membership functions for antecedent fuzzy variables.

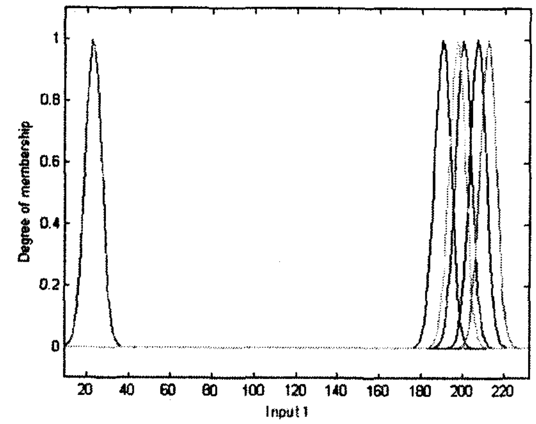
In order to develop the fuzzy model, input-output data are obtained from Subtractive clustering algorithms for IPI noise. Fuzzy rules for digital data of image are generated from clustering the input-output data. We obtained input-ouput data for image and image is 10800 by 8(8bit).

After clustering the data, 6 cluster centers and therefore 6 fuzzy rules are obtained for binary data of image. The 6 fuzzy rules for digital data are of the form:

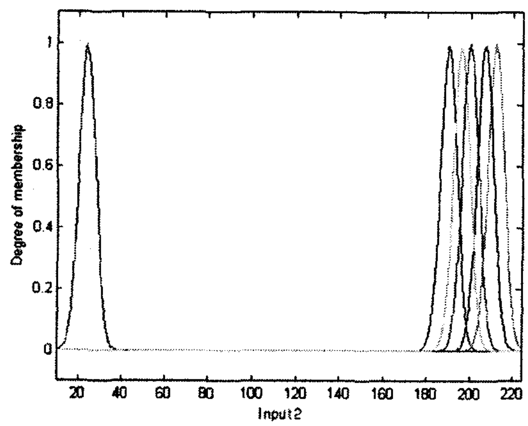
$$IF\ D_{TL}^k\ is\ A_{i1}, D_{TR}^k\ is\ A_{i2},\ D_{BL}^k\ is\ A_{i3},\ D_{BR}^k\ is\ A_{i4} \quad THEN\ D_{sum} = b_0 + b_1 D_{TL}^k + b_2 D_{TR}^k + b_3 D_{BL}^k + b_4 D_{BR}^k \ , \quad (i = 1,2,3,\cdots,6)$$

(4)

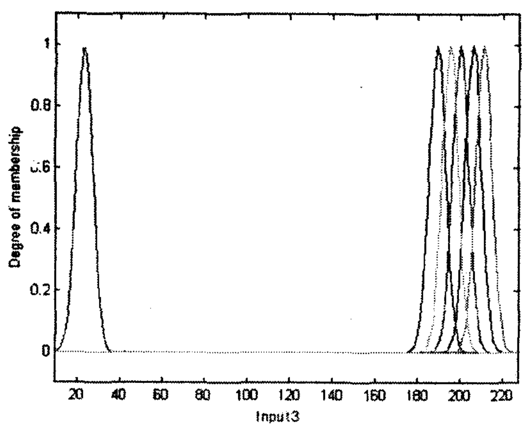
D_{sum} indicates Sum of D_{TL}, D_{TR}, D_{BL} and D_{BR}. Table 1 shows the 6 cluster centers and therefore the center locations of the 6 fuzzy rules. Gaussian input membership functions are shown in Fig. 7.



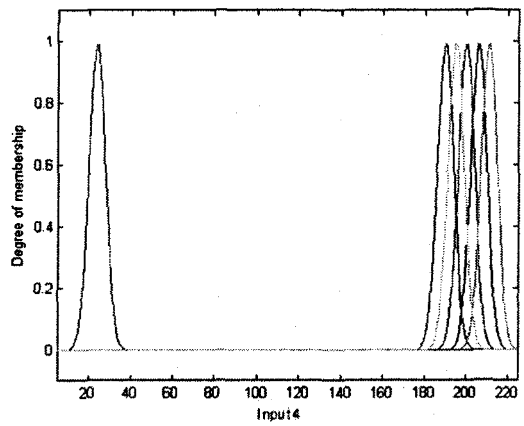
(a) Input membership function for Top-left image pixel



(b) Input membership function for Top-right image pixel



(c) Input membership function for Bottom-left image pixel



(d) Input membership function for Bottom-right image pixel

Figure 7: Input membership function of fuzzy systems

Fig. 7 shows input membership functions of fuzzy system.

Table 1. Cetner locations of the input membership functions for image pixels

Variables / Rules	A_{i1}	A_{i2}	A_{i3}	A_{i4}
1	207	209	205	205
2	201	202	201	201
3	193	192	190	189
4	210	214	212	212
5	233	242	231	241
6	199	198	196	194

4. Simulations

Fig. 8 is a data page made by applying IPI noise from 2-dimensional Fourier Transform to the original data page. After reconstruction the digital data from the data page with IPI noise with threshold method, 61 numbers of pixels are reconstructed different from the original pixels.

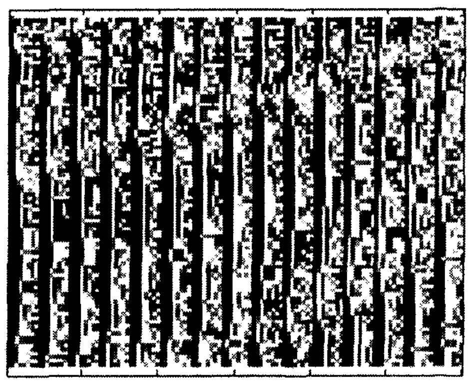


Figure 8: The original data page with IPI noise

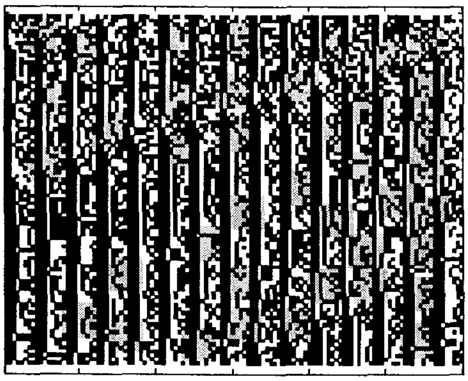
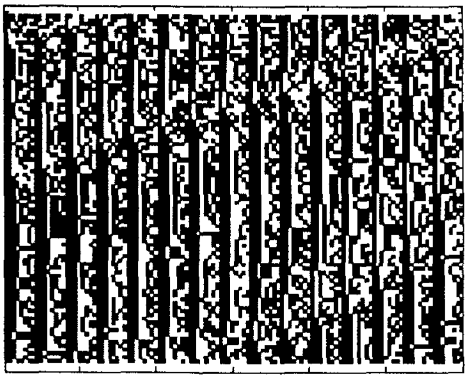
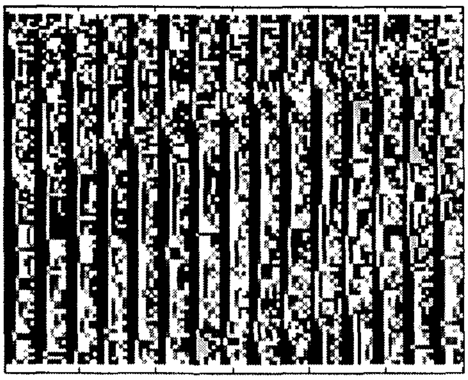


Figure 9: The modified data page

Fig. 9 is the modified data page with applying intensity reduction value to 9 by 9 pixels from the cluster centers in the center. Fig. 9 is the data page modified by suggested algorithm with IPI noise.



(a) Original data page



(b) Modified data page

Figure 10: Photographed images by CCD

Only 17 error pixels are found from reconstructed digital data of modified data page by threshold method.
Fig. 10(a) is the photographed image of the original data page by CCD camera and Fig. 10(b) is the image of modified data page. It can be perceived that intensity profile of the modified data page by applying suggested error reduction algorithm is more uniform than the original data page.

5. Conclusions

IPI noise is one of the main sources which induce errors in HDS system. And for accuracy in writing/retrieving processes, intensity profile of the data page to be stored is good as uniform as possible.
In this paper, by using subtractive clustering algorithm regions where there are many on-pixels in comparison are found and intensities of the pixels consist of the region are reduced by a specific value. Two main parameters - cluster radius and intensity reduction value - are optimized by DNA coding method. Therefore, the number of error pixels are reduced from 61 to 17 and intensity profile of the data page becomes uniform than before.

Acknowledgments

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