# 인공지능 기법을 이용한 홀로그래픽 데이터 스토리지 시스템의 에러 보정

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# Error Correction of Holographic Data Storage System Using Artificial Intelligence

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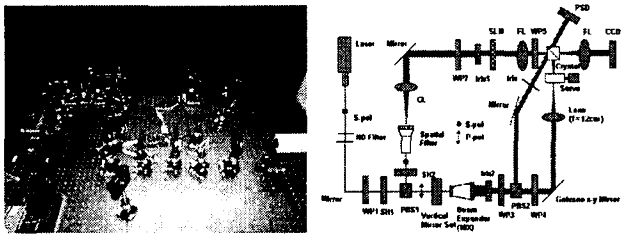
**Abstract** - Today any data storage system cannot satisfy all of these conditions, however holographic data storage system can perform faster data transfer rate because it is a page oriented memory system using volume hologram in writing and retrieving data. System can be constructed without mechanically actuating part therefore fast data transfer rate and high storage capacity about 1Tb/cm3 can be realized. In this research, to reduce errors of binary data stored in holographic data storage system, a new method for bit error reduction is suggested. Firstly, find fuzzy rule to use test bed system for Element of Holographic Digital Data System. Secondly, make fuzzy rule table using DNA coding method. Finally, reduce prior error element and recording digital data. Recording ratio and reconstruction ratio show good performance.

## 1. Introduction

Today many removable data storage media are shaped as disks. Especially almost all optical data storage systems have disk type media and the holographic data storage system(HDSS), one of the next generation optical memory system, also uses a disk type photopolymer medium. A Holograhpic data storage system has advantages of high data rate, rapid access and multiplexing method. The two-dimensional page-oriented nature of holographic data storage also utilizes the information capacity of an optical wavefront to allow data to be recorded and retrieved in parallel, a page at a time, rather than serially as in conventional storage[1][2].
This affords a potential for extremely high data rates subject only to limitations imposed by the I/O devices(SLM, detector arrays) and electronic channels. A further distinguishing feature is the speed by which data can be accessed[1]. In this paper, we Suggest a IPI noise reduction by the intelligence system based on fuzzy rules. IPI noise is a big issue of a holographic data storage system. The fuzzy theory is a method in an image processing suitable for a nonlinear system. A light beam intensity form is Gaussian and a nonlinear feature. This paper suggests a method to reconstruct data using fuzzy rules about the existing a retrieving data loss with IPI noise

## 2. A Structure of the holographic data storage system and IPI Noise

Fig. 1(a) illustrates a test bed structure of the holographic data storage system experimental bed. By the Fraunhofer diffraction theory, the beam from the laser source forms 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 the SLM allow the beam to pass through, but the off-pixels do not. So an on-pixel acts as an aperture, and the beam through the on-pixel of the SLM will affect to surrounding pixels by a 2-dimensional Fourier Transform[1][2].
This effect acts as one of the main noises sources, 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, errors from IPI noise will appear relatively higher than other areas of the data page[2]. Therefore if we find a cluster of on-pixels and reduce the intensities of the on-pixels around in a certain area of a data page, the possibility of error by IPI noise will decrease. Because the intensity of laser of the brighter areas will be decreased, a more uniform intensity profile will be obtained.



(a) (b)
**Fig.1 Experimental test bed and System architecture**

## 3. Fuzzy rules generated from clustering with DNA coding method

### 3.1 Clustering algorithm

Subtractive clustering[3] can identify fuzzy system models by determining cluster centers from the 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.

$$P_i = \sum_{k=1}^{N} \exp(-\alpha\|x_k - x_i\|^2) \tag{1}$$

$$P^{*1} = \max P_i \tag{2}$$

Here, $i = 1,\cdots,N$ and $\gamma_a$ is a positive constant to set data far apart from a cluster center so as not to influence on the potential value. The first cluster center $x_i^*$ corresponds to the largest potential value $P_i^*$. The second cluster center is calculated after removing the effect of the first cluster center. Eq.(3) shows how to remove the effect of the first cluster center. The second cluster center $x_2^*$ corresponds to the largest potential value of $P_i'$.

$$P_i' = P_i - P_i^* \exp(-\beta\|x_i - x_1^*\|^2), \quad \beta = 4/\gamma_a^2 \tag{3}$$

$$P^{*2} = \max P' \tag{4}$$

The positive constant $\gamma_b$ presents cluster centers from assembling to close. This process repeats until potential values reach a fixed limit $(\underline{\varepsilon}, \overline{\varepsilon})$. 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 $\alpha_{i1}, \alpha_{i2}, \cdots, \alpha_{in}$ can be optimized by linear least squares estimation or adaptive training algorithms.

### 3.2 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[3][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. The next step is to construct the proper structure of DNA code. In this paper we use input and n output fuzzy inference system. We use DNA coding method about optimize cluster radius size of Subtractive clustering parameter[8].

### 3.3 Generating fuzzy rules for error corrector of IPI noise

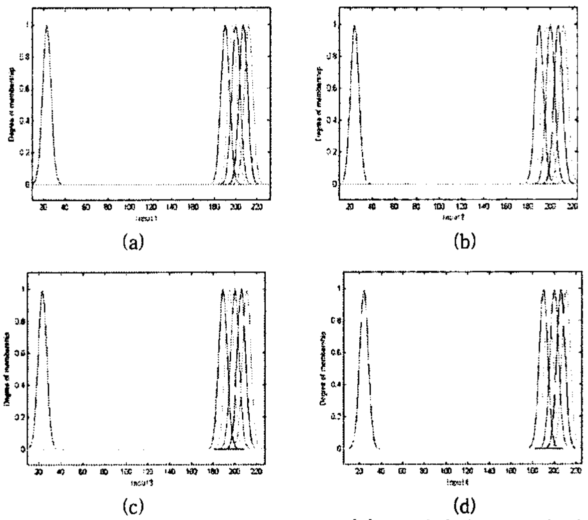
Sugeno fuzzy system model is used to represent the fundamental rules of group intelligence. The MISO type fuzzy rules are of the form given in Eq.(5).

$$\begin{aligned}&IF\ x_1\ is\ A_{i1}\ \text{and}\ x_2\ is\ A_{i2}\ \text{and},\cdots,\ x_n\ is\ A_{in}\\&THEN\ y_1 = a_{0i} + a_{1i}x_1 + \cdots + a_{ni}x_i\end{aligned} \tag{5}$$

$A_{ij}$ is Gaussian membership functions for input fuzzy variables, coefficients $a_{0i}, a_{1i}, \cdots, a_{ni}$ determine the output of the fuzzy system. The fuzzy modelling 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 the image are generated from clustering the input-output data. We obtained input-output data for a image which is 10800 by 8(8bit). After clustering the data, six cluster centers and therefore six fuzzy rules are obtained for the binary data of the image. Six fuzzy rules for digital data are of the
form:

$$\begin{aligned}&IF\ D^k_{TL}\ is\ A_{i1},\ D^k_{TR}\ is\ A_{i2},\ D^k_{BL}\ is\ A_{i3},\ D^k_{BR}\ is\ A_{i4}\\&THEN\ D_{sum} = b_0 + b_1 D^k_{TL} + b_2 D^k_{TR} + b_3 D^k_{BL} + b_4 D^k_{BR}\\&(i = 1,2,3,\cdots,6)\end{aligned} \tag{6}$$

$D_{sum}$ indicates the sum of $D_{TL}$, $D_{TR}$, $D_{BL}$ and $D_{BR}$. Table 1 shows the six cluster centers and therefore the center locations of six fuzzy rules. Gaussian input membership functions are shown in Fig. 2.

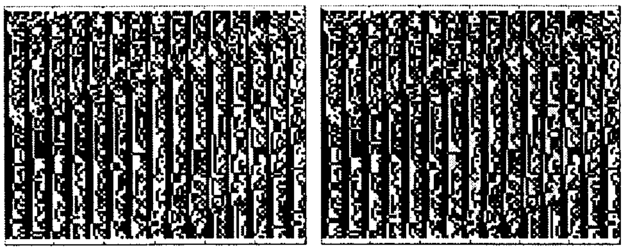


(a) (b) (c) (d)

**Fig.2 Input membership function:(a)Top-left image pixel (b)Top-right image pixel (c)Bottom-left image pixel (d)Bottom-right image pixel**

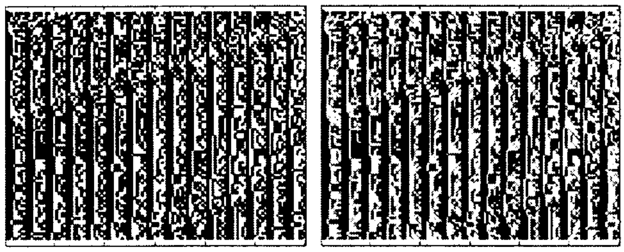
### 4. Simulations and Experiments

Fig. 3 shows a data page made by applying IPI noise from 2-dimensional Fourier transform of the original data page. After reconstruction the digital data from the data page with IPI noise with threshold method, 61 pixels turn-out to be incorrect.



(a) (b)

**Fig. 3 Original data and modify data**



(a) (b)

**Fig. 4 Original data and retrieving data**

Fig. 4(a) shows the photographed image of the original data page by a CCD camera and Fig. 4(b) shows the image of a modified data page. It can be perceived that intensity profile of the modified data page by applying the suggested error reduction algorithm is more uniform than the original data page.

### 5. Conclusions

The holographic data storage system (HDSS) is a strong candidate for a next generation data storage system. However to become a commercial information storage device, the HDSS has to solve several problems, for example noises source, size and cost, etc. In this paper, we apply intelligence algorithms to a holographic data storage system. The recording and retrieving process of a holographic data storage system is a good example for applying an artificial intelligence system. The fuzzy rules of a fuzzy system using DNA coding method can generate the writing and retrieving systems of a holographic data storage system. The fuzzy systems with a small number of fuzzy rules can greatly improve a holographic data storage system. In the future our research will include image processing of the data storage system, other system processes.

### Acknowledgments

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