홀로그래픽 저장장치에서 인접 페이지 간 간섭 모델링

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Modeling of the Inter-Page Interference on the Holographic Data Storage Systems

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요 약

홀로그래픽 저장장치는 여러 장의 데이터 페이지가 멀티플렉싱 기법에 의하여 같은 공간에 저장된다. 그러나 이러한 데이터 저장 밀도의 증가에 따라 페이지 데이터들이 서로에게 간섭이 된다. 같은 공간에 저장되는 모든 페이지들이 서로 간섭을 주게 되며, 그에 대한 영향력을 실험 과정에서 고려해야 한다. 따라서 본 논문에서는 이러한 페이지 간의 간섭에 대한 모델링을 하며, 그에 대한 성능을 분석한다.

Key Words : Holographic Data Storage(HDS), Inter-Page Interference(IPI), Partial-response Maximum Likelihood (PRML), Channel Modeling

ABSTRACT

The holographic data storage system stores multiple data pages by multiplexing. But the inter-page interference(IPI) caused by multiplexing reduces the intensity of the hologram. The simulation of the holographic storage systems has to consider the IPI. Therefore, we introduce a channel modeling that takes care of inter-page interference in the holographic data storage system. We simulate the performance of PRML detection on the hologrpahic data storage system with IPI modeling.

Ⅰ. Introduction

The holographic data storage system is a promising optical data storage technology because of its properties such as: high data storage density, high data rate, and short access times[1,2]. The data is stored in the form of two dimensional pages stacked within a volume of holographic material. The holographic data storage system is a page-oriented storage system. A whole page can be retrieved at once, and hundreds of pages can be recorded within the volume of holographic medium via multiplexing. Various multiplexing methods exist: angle multiplexing, shift multiplexing, wavelength multiplexing, etc. Angle multiplexing records different data pages by changing the angle of the reference beam. Shift multiplexing records multiple pages by using a reference beam consisting of a spectrum of plane waves[3,4].

Many problems exist when reading data on the holographic data storage system - e.g., inter-pixel interference, inter-page interference, misalignment of read data page, isolated pixel pattern, and diminishing light intensity at the edge of the page. Inter-page interference specifically increases the noise of the output and limits the storage capacity of

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a volume holographic storage system. Therefore, many researchers have studied ways to overcome the noises on the holographic data storage systems, such as: error correction codes, modulation codes, equalization method and detection methods[5-11].

We modeled the holographic data storage channel with inter-page interference by using several delay filters and their coefficients. We assume that the inter-page interference is the summation of the effect of the adjacent pages. We designed a delay filter of the page data in order to express the effect of inter-page interference. We can control the rate of inter-page interference via filter coefficients. We simulated the performance of partial-response maximum likelihood (PRML) on the holographic data storage channel with inter-page interference.

Ⅱ. The Inter-Page Interference on the Holographic Data Storage System

We know the parameter M/# that expresses the dynamic range performance of a holographic memory system[12]. For a large number of holograms M, the final equalized diffraction efficiency is

$$\eta=\left[\left(\frac{A_0}{\tau_r}\right)\frac{\tau_e}{M}\right]^2=\left(\frac{M/\#}{M}\right)^2 \tag{1}$$

A_0 is the saturation grating strength, τ_r is the recording time constant, τ_e is the erasure time constant, and we define M/# as

$$M/\#=\left(\frac{A_0}{\tau_r}\right)\tau_e \tag{2}$$

If M/# is increased, the system performance is improved because it achieves high diffraction efficiency. The high diffraction efficiency allows to store more data pages.

The holographic storage system stores multiple holograms until its diffraction efficiency limits, and thus has a high storage capacity. However, stored multiple holograms affect the other holograms. This effect is known as inter-page interference, or cross talk[13]. Figure 1 illustrates the holographic recording channel model with the proposed inter-page interference scheme. A_k is an input data page (1024 by 1024 pixels). k denotes an index of holograms (k is 1 to N). H_{IPI} is the proposed inter-page interference channel model.

The inter-page interference is caused by a disturbance from the neighbor holograms. For example, the holographic data storage system has N holograms within a volume of holographic material. Therefore, the N holograms affect the other holograms. However, in computer simulation, a high N value is not advisable because the computer needs to memorize the page data of N holograms. Figure 2 illustrates the inter-page interference model with its coefficients β when the number of holograms is N. Because the size of page is 1024 by 1024, and the number of holograms is N, $1024*1024*N$ memories are needed for the simulation.

Therefore we suggest a simple inter-page interference model consisted of several delay filters and its filter coefficients to reduce memory. Figure 3 shows that the proposed inter-page interference model has five delay taps and their coefficients β. For simulation, it is necessary to decide the parameter β. β denotes the side effect of the adjacent holograms at the Bragg null[14,15].

The intensity of the first sidelobe is about 6% and

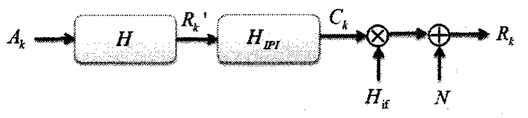

Fig. 1. Holographic data storage system channel model with the proposed inter-page interference model

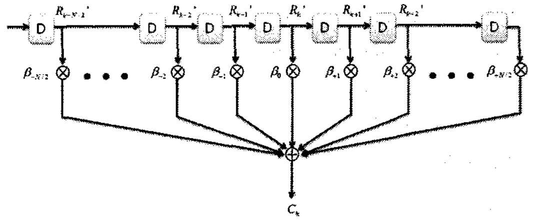

Fig. 2. Inter-page interference model using N filters and its coefficients β

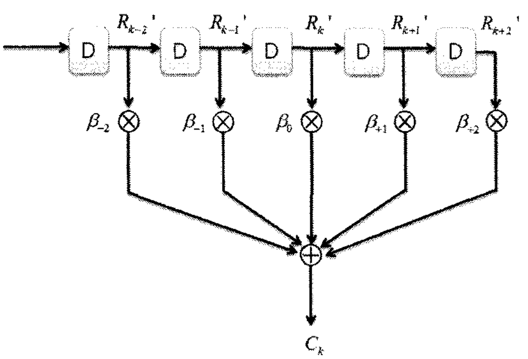

Fig. 3. Proposed inter-page interference model using five filters and its coefficients β

the second sidelobe is about 3% in an angular multiplexing system[14]. Using the single point source, the diffraction efficiency is plotted to compare with the intensity of the first sidelobe of about 5.0% in a shift multiplexing system[15].

Ⅲ. HDS Channel Modeling for Simulation

We modeled channel effects which include: inter-page interference, inter-pixel interference, and the diminishing light intensity at the edge of a page. The holographic recording channel model using the continuous point spread function (PSF) is given by[16]

$$h(x,y) = \frac{1}{\sigma_b^2} sinc^2\left(\frac{x}{\sigma_b}, \frac{y}{\sigma_b}\right) \quad (3)$$

where $\mathrm{sinc}(x,y) = (\mathrm{sinc}(\pi x)/\pi x)(\mathrm{sinc}(\pi y)/\pi y)$, and σ_b is the degree of the blur.

$$h[p,q] = \int_{q-1/2}^{q+1/2} \int_{P-1/2}^{P+1/2} h(x,y)dxdy \quad (4)$$

where $h[p,q]$ is the discrete point spread function.

$$r[p,q] = h_{\mathrm{if}}[p,q] \sum_{j=-2}^{j=+2} (\beta_j (d[p,q] \otimes h[p,q])_j) + n[p,q] \quad (5)$$

where $d[p,q]$ is the input data, $\otimes$ denotes the two dimensional convolution sum operation, and $n[p,q]$ is the additive white Gaussian noise (AWGN). Coefficient β_j expresses the effect of inter-page interference, and j is an index of the neighbor holograms. In this simulation, we consider the previous two pages and next two pages, thus, j is from -2 to 2. We consider the range of the discrete point spread function as the 5 by 5 array pixels. Also, we took into consideration the diminishing light intensity phenomenon at the edge of the page; $h_{\mathrm{if}}[p,q]$ is the diminishing channel and the intensity factor (IF) controls the degree of diminishing[17]. The BER performance depends on the degree of the intensity factor - the performance is good when the intensity factor is large.

We define the channel signal-to-noise ratio (SNR) as

$$SNR = 10\log_{10}\left(\frac{1}{\sigma_w^2}\right) \quad (6)$$

where σ_w^2 is the AWGN noise power.

Ⅳ. Simulation Results

In the holographic data storage system, the detection of the stored data is usually done by the partial-response maximum likelihood detection, which employs an equalizer and Viterbi detector. The coefficients of the equalizer are updated by the least mean square (LMS) algorithm. We investigated the BER performance of the partial-response maximum likelihood detection. The simulation parameters are as follows: the number of pages is 1000 and the size of the page is 1024 by 1024 pixels. The degree of blur is 1.4, and the x- and y-axis misalignments are 10% and 10%, respectively. The equalizer adapts the channel to the PR(191) target.

We simulated the performance of various channel models. The first channel model includes AWGN only, and the second channel model includes the diminishing light intensity phenomenon with the first channel model. The last channel model includes the proposed inter-page interference with the second channel model. Figure 4 shows the BER performance of the three channels which include the diminishing light intensity phenomenon and the inter-page interference, which must be taken into consideration in the holographic recording simulation. When there is no inter-page interference, the holographic data storage system performs 0.6 and 1.1 dB better than the system with IPI (0.02 0.05 1 0.05 0.02) and IPI (0.03 0.06 1 0.06 0.03), respectively (the intensity factor was 3.0).

We also simulated the performance when the intensity factors are 3.0, 5.0, and without degradation of light intensity at the edges. These performances are simulated when the inter-page interference coefficient $(\beta_{-2},\beta_{-1},\beta_0,\beta_1\beta_2)$ is (0.02 0.05 1 0.05 0.02) and (0.03 0.06 1 0.06 0.03), as

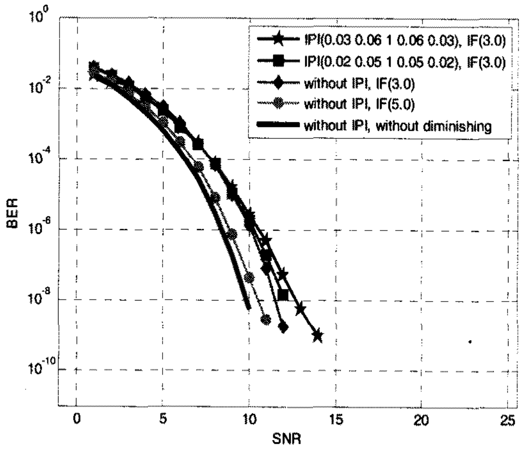

Fig. 4. Simulation results of various channel models

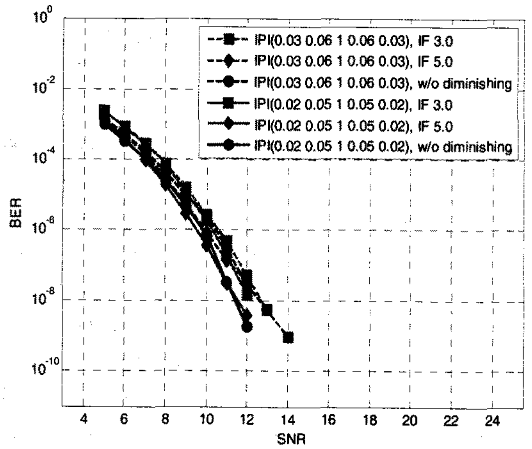

Fig. 5. Simulation results of the proposed inter-page interference channel model

explained in Section 2. Figure 5 shows the performances of different inter-page interference values in the holographic data storage system.

Based on these results, the inter-page interference is a crucial factor in decreasing the BER performance in the holographic data storage systems. That is why we should take into account the inter-page interference in the holographic recording channel.

V. Simulation Results

To simulate processes that take inter-page interference into account, the conventional method requires huge memory because multiple pages affect each other. In this paper, we introduce a simple inter-page interference model using finite filters and their coefficients, which requires less memory and makes the inter-page interference model simpler. It is a convenient channel model in terms of testing signal processing and coding. In this simulation we memorized the data of five pages, and the coefficients of filters were decided by other papers. This simple inter-page interference channel model can easily adapt to the simulation in the holographic recording channel model.

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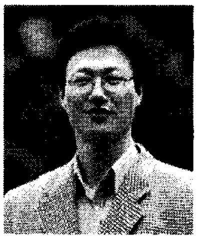

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