엇갈린 형태의 비트 패턴드 미디어 기록장치를 위한 PRML 성능 평가

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Performance Evaluation of PRML for Staggered Bit-Patterned Media Recording

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요 약

비트 패턴드 미디어 기록장치는 기록밀도를 4 Tb/in^{2}까지 저장이 가능하기 때문에 차세대 데이터 저장장치로 주목받고 있다. 비트 패턴드 미디어 기록장치의 저장용량을 증가시키기 위해서는 비트 섬들의 간격이 좁아져야한다. 그러나 비트들간의 간격이 좁아짐에 따라 가로 방향의 인접 심볼간 간섭 뿐만 아니라 세로 방향의 인접 트랙간 간섭이 심각하게 발생하여 비트 패턴드 미디어 기록장치의 성능을 저하시킨다. 즉, 2차원 인접 심볼간 문제가 심각하게 발생한다. 비트 패턴드 미디어 기록장치의 비트 섬들의 배열을 일반적인 형태 혹은 엇갈린 형태로 위치시킬 수 있다. 엇갈린 형태를 사용한 비트 패턴드 미디어는 일반적인 형태를 사용한 비트 패턴드 미디어보다 인접 트랙간 간섭의 영향을 줄일 수 있기 때문에 향상된 성능을 얻을 수 있다. 본 논문에서는 엇갈린 형태의 비트 패턴드 미디어 기록장치를 위한 가로 방향과 세로방향의 1차원 연판정 출력 비터비 알고리즘(soft output Viterbi algorithm, SOVA)을 이용한 2차원 SOVA을 제안하며, PR타겟을 변경한 성능을 확인한다.

Key Words : bit-patterned media recording, data storage systems, partial response maximum likelihood, signal detection, soft-output Viterbi algorithm

ABSTRACT

Bit-patterned media recording (BPMR) is widely recognized as a promising storage technology for the future magnetic recording systems to extend the densities of up to 4 Tb/in^2. For increasing a density of BPMR, the bit islands must be close to each other. Since the distance between bit islands becomes smaller, there will be more inter-symbol interference (ISI) in addition to inter-track interference that severely degrades the performance of BPMR system; in other words, we have faced the problem of two-dimensional (2-D) ISI. In BPMR, bit islands can be arranged on a regular array or packed in a staggered pattern. Since the effect of the ITI can be diminished by using staggered pattern, it can achieve better performance than that of using regular pattern. In this paper, we propose a 2-D soft output Viterbi algorithm (SOVA) with horizontal and vertical 1-D SOVA for staggered pattern islands BPMR. Also, we investigate the performance of different partial response targets, comparing horizontal 1-D SOVA and 2-D SOVA.

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Ⅰ. Introduction

Since data has been increasing explosively in information age, storage system which can record a lot of data is needed. However, since hard disk drive (HDD) technology encounters problems such as thermal stability, super-paramagnetic limit and so on, HDD is encountered with areal density (AD) limit. To surmount these problems, bit-patterned media recording (BPMR) has been developed[1]. Since BPMR employs separated single-domain magnetic islands to store information (i.e., the BPMR stores one bit in one island.), it can offer thermal stability and decrease transition noise[2]. As a result, BPMR is one of candidate for the next generation magnetic storage system to extend AD of up to 4 terabit per square inch (Tb/in^2)[3]. According to lithography method adopted, bit-patterned media (BPM) structures (bit position pattern) can be placed in a rectangular aligned (regular array) or trigonal half-delayed BPM (staggered array) layout as shown Fig. 1. When the islands are placed hexagonally in the staggered array, the bit error rate (BER) performance of using staggered array as shown in Fig. 1(b) is better than that of using regular array as shown in Fig. 1(a) due to reduced inter-track interference (ITI)[4,5].

For increasing AD of BPMR, the bit period and track pitch must be shorter. However, since the distance between data bit islands in the down- and cross-track directions become narrower, there will be more inter-symbol interference (ISI) in addition to ITI that significantly deteriorate the overall BPMR system performance; in other words, we must consider and resolve the problem of two-dimensional (2-D) ISI. Also fabrication imperfections in BPM can result in the problems of media noise such as location and size fluctuations.

From a signal processing perspective, signal processing schemes such as error-correcting codes, modulation codes, and signal detection schemes are required to overcome these error factors and recover the recorded data. There are error correcting codes such as Reed-Solomon (RS) code and low-density parity check (LDPC) code to improve BER performance[6,7]. Especially, LDPC code is outstanding in digital communication and storage systems. To forestall error patterns that affect performance degradation of storage systems, modulation codes have been proposed[8-11]. In recording system, the most famous signal detection scheme is partial response maximum likelihood (PRML) detection. PRML refers to a storage systems where the channel response is equalized to a partial response (PR) pulse shape and maximum likelihood (ML) sequence detector (here, a Viterbi detector) is employed to further detect the input data[12,13].

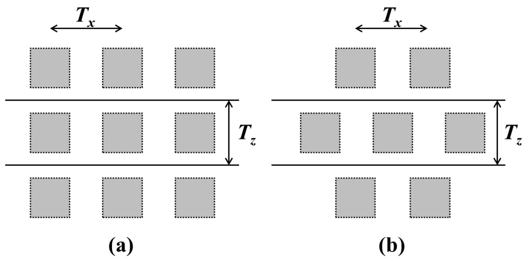

그림 1. BPM 레이아웃의 배열((a) 일반적 형태의 배열, (b) 어긋난 형태의 배열)
Fig. 1. Arrangements of the BPM layout. (a) regular layout, (b) staggered layout.

In this paper, we propose a 2-D soft output Viterbi algorithm (SOVA) which consists of horizontal and vertical 1-D SOVAs for BPMR of staggered pattern islands layout. Also, we investigate the performance of different partial response targets comparing horizontal 1-D SOVA and 2-D SOVA.

Ⅱ. BPMR Channel Modeling

For the study in this paper, we use the 2-D Gaussian island pulse response $P(x, z)$ with the location fluctuations as

$$P(x,z) = Aexp\left\{-\frac{1}{2c^2}\left[\left(\frac{x+\Delta x}{PW_x}\right)^2+\left(\frac{z+\Delta z}{PW_z}\right)^2\right]\right\} \quad (1)$$

where x and z are the down- and cross-track directions, respectively; Δx and Δz are the bit location fluctuations (bit position jitter) of the down- and cross-track, respectively; c is a constant represented by the relationship between the standard deviation of a Gaussian function and PW50 (PW50 = 2.3548 × standard deviation), i.e., c = 1/2.3548; and PW_x and PW_z are the PW50 of the down- and cross-track pulses, respectively[14,15]. PW50 is a parameter designated as the pulse width at half of the peak amplitude. The 2-D channel response coefficients $h(m, n)$ can be gained by sampling the isolated island pulse as follows

$$h(m,n) = P(nT_x, mT_z + \triangle_{off}) \tag{2}$$

where T_x, T_z and Δ_{off} are the bit period, track pitch and read head offsets, respectively. Recording heads generally do not maintain at the center of data track, but rather be near the center of the data track, causing so-called track mis-registration (TMR). TMR is defined as the read head offset divided by the track pitch, written as follows[9]

$$TMR(\%) = \frac{\triangle_{off}}{T_z} \times 100. \tag{3}$$

The readback signal $r[m, n]$ for trigonal half-delayed BPM layout is defined by

$$\begin{aligned} r[p,q] &= d[p,q] \otimes h(m,n) + n[p,q] \\ &= \sum_{n=-N}^{N} d[p,q+n] \cdot h(m,n) \\ &+ \sum_{m=0}^{\lfloor (N-1)/2 \rfloor} \sum_{n=-N+m+1}^{N-m} d[p-(2m+1),q+n] \cdot h(n-\tfrac{1}{2}, -(2m+1)) \\ &+ \sum_{m=0}^{\lfloor (N-1)/2 \rfloor} \sum_{n=-N+m+1}^{N-m} d[p+(2m+1),q+n] \cdot h(n-\tfrac{1}{2}, (2m+1)) \\ &+ \sum_{m=1}^{\lfloor N/2 \rfloor} \sum_{n=-N+m}^{N-m} d[p-2m,q+n] \cdot h(n,-2m) \\ &+ \sum_{m=1}^{\lfloor N/2 \rfloor} \sum_{n=-N+m}^{N-m} d[p+2m,q+n] \cdot h(n,2m) + n[p,q] \end{aligned} \tag{4}$$

where $d[p, q]$ is a 2-D array of binary input data; $h(p, q)$ is the 2-D channel response; $n[p, q]$ is an additive white Gaussian noise (AWGN) with zero mean and variance σ^2; ⊗ is 2-D convolution operator; N is the length of interference from neighboring islands according to N in trigonal half-delayed BPM layout described shown as Fig. 2.

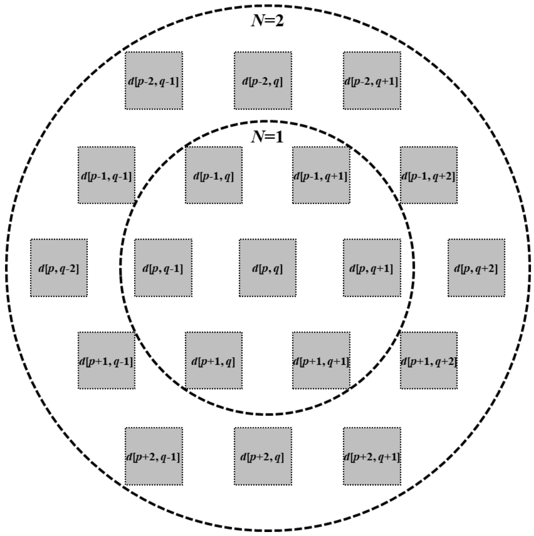

그림 2. 어긋난 형태의 BPMR에서 길이 N에 따른 주변픽셀들의 2차원 간섭
Fig. 2. 2-D Interference from neighboring islands in accordance with length N in staggered BPMR.

Ⅲ. Proposed 2-D Symbol Detection

Fig. 3 shows the block diagram of the proposed 2-D symbol detection system for staggered island position BPMR. The input data $d[p, q]$ are 2-D array of random binary data. $r[p, q]$ is readback signal with $n[p, q]$ of AWGN. After passing through the staggered BPMR channel, $r[p, q]$ is inputted to horizontal and vertical equalizer. $z_x[p, q]$ and $z_z[p, q]$ of horizontal and vertical equalizer outputs inputted to horizontal and vertical SOVA, respectively. The 2-D SOVA output is obtained by averaging the output of horizontal and vertical 1-D SOVAs. The horizontal equalizer and SOVA are only considered for 1-D SOVA symbol detection. (i.e., ignore the vertical equalizer and SOVA).

In this paper, we consider four cases. Case (1):

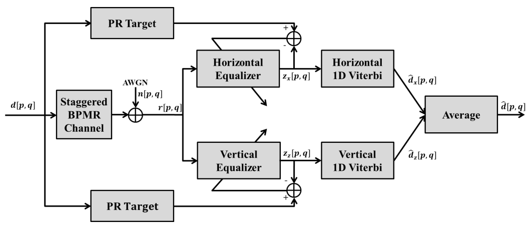

그림 3. 제안하는 방식의 블록 다이어그램
Fig. 3. Block diagram of the proposed scheme.

horizontal 1-D SOVA with PR (0.1, 1, 0.1), Case (2): horizontal 1-D SOVA with PR (0.2, 1, 0.2), Case (3): 2-D SOVA (horizontal 1-D SOVA and vertical 1-D SOVA) with PR (0.1, 1, 0.1), respectively, Case (4): 2-D SOVA (horizontal 1-D SOVA and vertical 1-D SOVA) with PR (0.2, 1, 0.2), respectively.

Ⅳ. Simulation and Results

In this simulation, we used the down-track PW_x of 19.4 nm and cross-track PW_z of 24.8 nm. The bit period and track pitch are 18 nm, respectively. Signal-to-noise ratio (SNR) is defined as SNR = $10\log10(1/\sigma^2)$ in decibel (dB). The 2-D equalizer is performed by finite impulse response and has 5×5 coefficients. The coefficients of 2-D equalizer are updated by a least mean square algorithm. Fig. 4 illustrates BER performance of the proposed 2-D SOVA according to PR target and SNR. When BER=10^{-4}, Case (4) performs better than Case (3) by 0.2 dB, Case (1) by 0.7 dB, and Case (2) by 1.2 dB, respectively. Fig. 5 shows BER performance of the proposed 2-D SOVA according to PR target and location fluctuation. When BER=10^{-4} and location fluctuation was 5%, the performance of Case (4) was better than Case (3) by 0.2 dB, Case (1) by 0.7 dB, and Case (2) by 1.3 dB, respectively. This trend at a location fluctuation of 5% was also shown at a location fluctuation of 10%. Fig. 6 shows BER performance of the proposed 2-D SOVA according

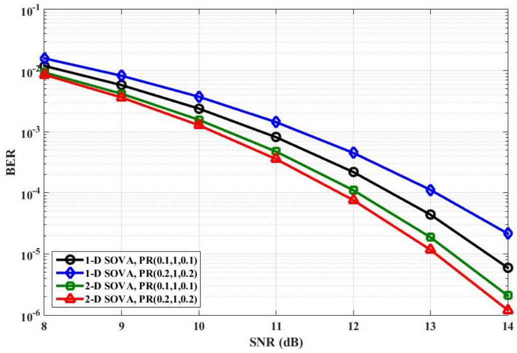

그림 4. SNR과 PR타겟에 따른 제안하는 2차원 SOVA의 BER 성능 그래프
Fig. 4. BER performance of the proposed 2-D SOVA in accordance with SNR and PR target.

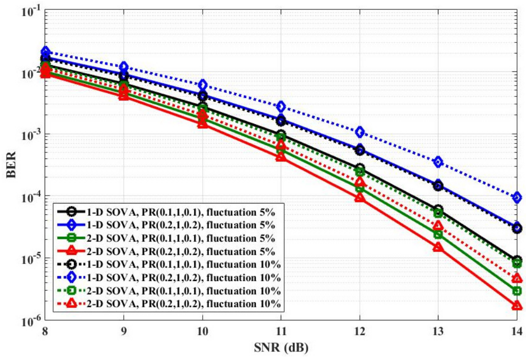

그림 5. fluctuation과 PR타겟에 따른 제안하는 2차원 SOVA의 BER 성능 그래프
Fig. 5. BER performance of the proposed 2-D SOVA in accordance with fluctuation and PR target.

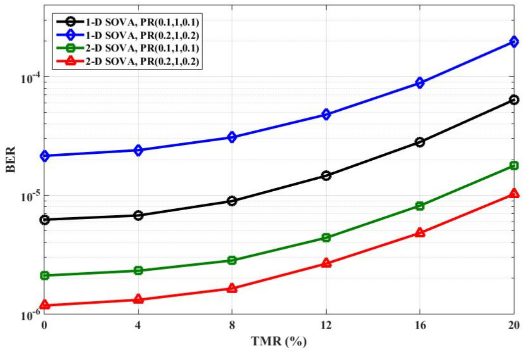

그림 6. TMR과 PR타겟에 따른 제안하는 2차원 SOVA의 BER 성능 그래프
Fig. 6. BER performance of the proposed 2-D SOVA in accordance with TMR and PR target.

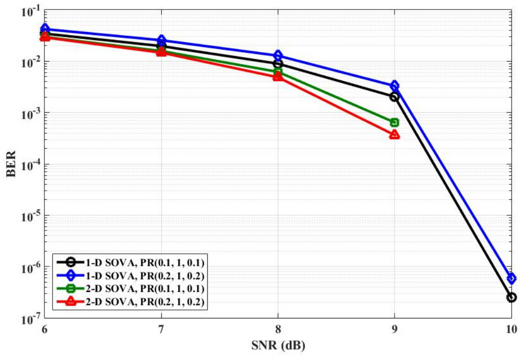

그림 7. 제안하는 2차원 SOVA를 이용한 LDPC의 BER 성능 그래프
Fig. 7. BER performance of the LDPC codes with proposed 2-D SOVA.

to PR target and TMR when SNR=14 dB. Also, Case (4) performed better than other cases. Fig. 7 shows the BER performance of the proposed 2-D

SOVA with LDPC code. Case (4) showed the best performance among these, and the performance pattern seen was similar to the results before.

V. Conclusion

In this paper, we proposed a 2-D SOVA using two 1-D SOVAs for BPMR of staggered island pattern and investigated the performance of PR targets by comparing horizontal 1-D SOVA and 2-D SOVA. The PR target of PR(0.2, 1, 0.2) exploiting 2-D SOVA performs better than the other cases.

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