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Iterative decoding of SOVA and LDPC product code for bit-patterned media recoding

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The demand for high-density storage systems has increased due to the exponential growth of data. Bit-patterned media recording (BPMR) is one of the promising technologies to achieve the density of 1Tbit/in^2 and higher. To increase the areal density in BPMR, the spacing between islands needs to be reduced, yet this aggravates inter-symbol interference and inter-track interference and degrades the bit error rate performance. In this paper, we propose a decision feedback scheme using low-density parity check (LDPC) product code for BPMR. This scheme can improve the decoding performance using an iterative approach with extrinsic information and log-likelihood ratio value between iterative soft output Viterbi algorithm and LDPC product code. Simulation results show that the proposed LDPC product code can offer 1.8dB and 2.3dB gains over the one LDPC code at the density of 2.5 and 3 Tb/in^2, respectively, when bit error rate is 10^{-6}. https://doi.org/10.1063/1.5003429

I. INTRODUCTION

Bit-patterned media recording (BPMR) is a future magnetic storage system that overcomes this limitation and accomplishes high densities of up to 4 Tb/in, since each bit is stored in a separate single-domain magnetic island. Furthermore, BPMR has the merits of reducing the nonlinear transition shift and increasing thermal stability, because the space between the magnetic islands is nonmagnetic.[1] To achieve higher areal densities (ADs), the spacing between the bit islands in the along- and cross-tracks needs to be reduced. This means that the inter-magnetic islands must be close to each other. We therefore need to consider two-dimensional (2-D) interference comprising horizontal inter-symbol interference (ISI) and vertical inter-track interference (ITI), unlike conventional magnetic storage systems. Thus, 2-D ISI needs to be managed; i.e. ISI and ITI must be considered simultaneously. Also, media noise such as the fluctuation of the location of islands and the fluctuations of the size of islands occur in BPMR.[2] These error factors considerably degrade the system performance of the BPMR channels. In order to mitigate these error factors, various schemes have been proposed such as modulation code, signal detection, and error-control coding. To improve the overall system performance, various error-control coding schemes such as the low-density parity check (LDPC) code and the Reed-Solomon (RS) code have been proposed, whereby the LDPC code is the most popular error-control coding for storage systems.[3] A 9/12 modulation coding has been introduced to eliminate 2-D ISI in BPMR.[4] Also, an iterative 2-D soft output Viterbi Algorithm (SOVA) consisting of horizontal and vertical 1-D SOVA has been proposed.[5] The detection algorithm improves the performance of the BPMR by using more extrinsic information.

In this work, we present the iterative decoding of the SOVA and LDPC product codes for BPMR. Various product code schemes have also been proposed.[6] The output of a first encoder arranged as rows of a rectangular array is fed into the input of a second encoder arranged as the column of a rectangular array, and so on. We use iterative 2-D SOVA and LDPC product code, comprising two

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systematic LDPC codes for the horizontal and vertical directions, respectively, using the extrinsic information. To evaluate the overall BPMR system performance of the proposed iterative decoding of the SOVA and LDPC product codes, it is compared with a conventional LDPC code with similar code rates.

II. PROPOSED LDPC PRODUCT CODING SCHEME

A block diagram of the proposed iterative SOVA and LDPC product codes is shown in Fig. 1. The proposed encoding structure of the LDPC product code is comprised of the horizontal and vertical directions of the LDPC encoder. After the encoded data has been passed through the BPMR channel and the 2-D equalizer, the proposed decoding process begins, as follows. (1) First, we apply the iterative 2D-SOVA algorithm.[5] (2) Detected data $S_a[p,q]$ from 2D-SOVA are decoded by the horizontal LDPC (HL) decoder. The log-likelihood ratio (LLR) value $L_{h1}[p,q]$ from HL is then transmitted to the vertical LDPC (VL) decoder. (3) Using $S_a[p,q]$ and $L_{h1}[p,q]$, the VL decoder outputs the LLR value $L_{v1}[p,q]$ and passes it to the HL decoder. (4) Using $S_a[p,q]$ and $L_{v1}[p,q]$, the HL decoder outputs $L_{h2}[p,q]$. (5) Then, the LLR values, $L_{h2}[p,q]$ and $L_{v1}[p,q]$, are sent to the horizontal SOVA (HS) and the vertical SOVA (VS), respectively. (6) HS and VS then decode $E_h[p,q]$ and $E_v[p,q]$ with a small hard-limited value of $L_{h2}[p,q]$ and $L_{v1}[p,q]$, respectively. Then, HS and VS decode $E_h[p,q]$ and $E_v[p,q]$ with a small hard-limited value of $S_v[p,q]$ and $S_h[p,q]$, respectively. (7) The steps from (2) to (4) are then repeated and the VL decoder using $S_a[p,q]$ and $L_{h2}[p,q]$ outputs the estimated data.

III. SIMULATION AND RESULTS

For recording binary input data into a medium, we use the discrete BPMR channel model.[4] 2-D Gaussian pulse response $P(x, z)$ that includes the media noise effect is defined by

$$P(x,\ z) = A\exp\left\{-\frac{1}{2c^2}\left[\left(\frac{x+\Delta_x}{\mathrm{PW}_x}\right)^2+\left(\frac{z+\Delta_z}{\mathrm{PW}_z}\right)^2\right]\right\} \tag{1}$$

where x and z are the along- and across-track directions, respectively; Δ_x and Δ_z are the along- and across-track location fluctuations; $c = 1/2.3548$; and PW_x and PW_z are the PW50 of the along- and across-track pulse, respectively. The track mis-registration (TMR) for the along- and across-track is defined as $\mathrm{TMR}_x=\Delta_{x\text{-off}}/T_x$ and $\mathrm{TMR}_z=\Delta_{z\text{-off}}/T_z$, respectively, where $\Delta_{x\text{-off}}$ and $\Delta_{z\text{-off}}$ are the read head offsets for the along- and across-tracks, respectively.[6] The 2-D channel response coefficients $h[m, n]$ can be obtained by sampling the isolated island pulse response at the integer multiples of T_x (bit period) and T_z (track pitch) such as $h[m, n]=\mathrm{P}(mT_x - \Delta_{x\text{-off}}, nT_z - \Delta_{z\text{-off}})$, where $-M \le m \le M$, $-N \le n \le N$. However, since $P(mT_x , nT_z)$ is almost zero for $mT_x \ge 2T_x$ and $nT_z \ge 2T_z$, we set $m = n = 1$ for simplicity. The readback signal $r[m, n]$ is defined by

$$r[p,\ q] = d[p,\ q]\otimes h[p,\ q] + n[p,\ q] = \sum_{m=-1}^{1}\sum_{n=-1}^{1} d[p-m,\ q-n]h[m,n] + n[p,q] \tag{2}$$

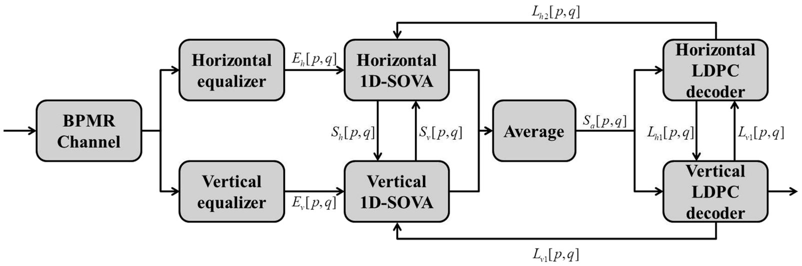

FIG. 1. Block diagram of the proposed iterative SOVA and LDPC product codes.

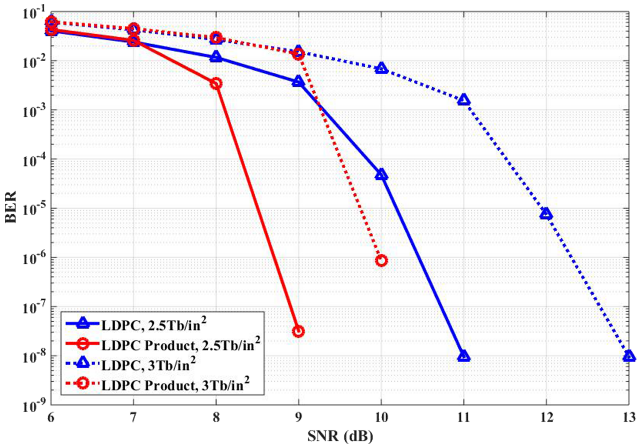

FIG. 2. BER performance of the proposed LDPC product code according to SNR.

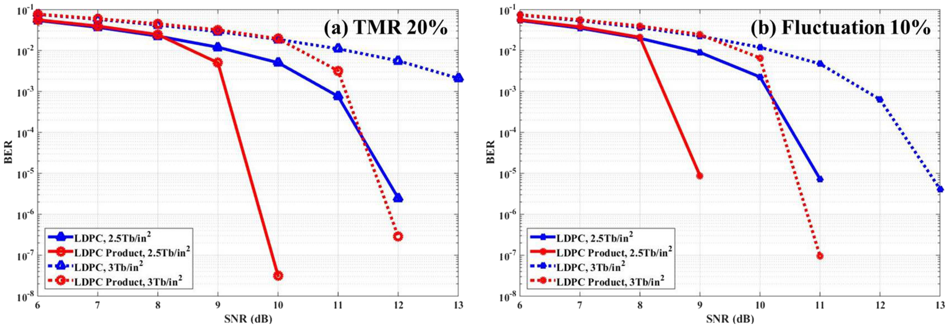

FIG. 3. BER performance of the proposed LDPC product code in accordance with SNR (a) TMR of 20% and (b) location fluctuation of 10%.

where $d[p,q]$, $h[p,q]$, $n[p,q]$, and $\otimes$ are the 2D discrete input data, 2D discrete time island response, additive white Gaussian noise (AWGN) with variance σ^2 and zero mean, and 2D convolution operation, respectively. In this simulation the page size of the BPMR-channel input data is 1084×1084. We compare the proposed LDPC product code of $(4336, 4096) \times (4336, 4096)$ to an LDPC code of (4336, 3856) on the BPMR channel. The partial-response (PR) target is $\{(0.0, 0.2, 0.0), (0.1, 1.0, 0.1), (0.0, 0.2, 0.0)\}$. The overall code rates of one LDPC code and the proposed LDPC product code are 0.889 and 0.892, respectively. The decoding algorithm that is used for the LDPC decoder is the standard sum-product algorithm in the log domain. Fig. 2 shows the bit error rate (BER) performance of the proposed scheme according to the signal-to-noise ratio (SNR). When the densities are 2.5Tb/in^2 and 3Tb/in^2, the performance of the proposed scheme is 1.8dB and 2.3dB better than that of one LDPC code at 10^{-6} BER, respectively.

Fig. 3 displays the BER performance of the proposed LDPC product code in accordance with SNR at TMR 20% and the location fluctuation of 10%. At the BER of 10^{-6}, the performance of the proposed LDPC product code at the TMR of 20% is approximately 2.1dB better than that of the one LDPC code. Similarly, the location fluctuation of 10% indicates a comparable tendency.

IV. CONCLUSION

In this paper, we proposed an iterative decoding of the iterative 2-D SOVA and LDPC product codes for BPMR. The proposed scheme, which exploits iterative 2-D SOVA and two LDPC codes for the horizontal and vertical directions, respectively, with extrinsic information, performs better than the one LDPC coding scheme having a similar overall code rate. Since the iterative 2-D SOVA delivers more accurate LLR values to the LDPC product code than the 2-D SOVA and the extrinsic information is iteratively transmitted between the iterative 2-D SOVA and LDPC product codes, the proposed LDPC product code shows better performance than the case of the one LDPC code.

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