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4 authors, including:


Chanon Warisarn
King Mongkut's Institute of Technology Ladkrabang


Pornchai Supnithi
King Mongkut's Institute of Technology Ladkrabang


Piya Kovintavewat
Nakhon Pathom Rajabhat University

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C. Warisarn, T. Losuwan, P. Supnithi, and P. Kovintavewat

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An iterative inter-track interference mitigation method for two-dimensional magnetic recording systems

C. Warisarn,[1] T. Losuwan,[1] P. Supnithi,[2] and P. Kovintavewat[3,a)]
[1]*College of Data Storage Innovation, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand*
[2]*Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Bangkok 10520, Thailand*
[3]*Data Storage Technology Research Center, Nakhon Pathom Rajabhat University, Nakhon Pathom 73000, Thailand*

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At high recording density, the readback signal of two-dimensional magnetic recording is inevitably corrupted by the two-dimensional (2D) interference consisting of inter-symbol interference and inter-track interference (ITI), which can significantly degrade the overall system performance. This paper proposes an iterative ITI mitigation method using three modified 2D soft-output Viterbi algorithm (2D-SOVA) detectors in conjunction with an iterative processing technique to combat the 2D interference. The codeword of the outer code is divided and then written on three separate tracks. For every iteration, all 2D-SOVA detectors exchange the soft information to improve the reliability of the *a priori* information and use it in the branch metric calculation, before feeding the refined soft information to the outer decoder. Simulation results show that the proposed method outperforms the conventional receiver and the existing partial ITI mitigation method. © *2014 AIP Publishing LLC*. [http://dx.doi.org/10.1063/1.4866849]

I. INTRODUCTION

Two-dimensional magnetic recording (TDMR) by shingled magnetic recording[1] is a promising technology for realizing an areal density (AD) toward 10 Tb/in^2, which attempts to store one channel bit in few grains of a magnetic medium so as to reach about 1/2 data bits per grain.[1] When reproducing a shingle-recorded data sequence by a wide reader, the readback signal is severely corrupted by the two-dimensional (2D) interference, consisting of inter-symbol interference and inter-track interference (ITI), which can deteriorate the system performance considerably. Generally, there are two techniques proposed to mitigate the 2D interference, namely, an ITI cancellation method[2,3] and a multi-track detection method.[4,5] For example, a partial ITI mitigation method (PIMM)[2] used the bit estimates from the low-density parity-check (LDPC)[6] decoder as partial ITI estimates for the branch metric calculation in the modified soft-output Viterbi algorithm (SOVA)[7] detector. In addition, the multi-track detection[4] was introduced to recover only the user data on the center track, but did not mention how to recovery the user data from adjacent tracks in a multi-track recording system. This paper proposes an iterative ITI mitigation method to alleviate the severe 2D interference in a coded TDMR channel.

II. CHANNEL MODEL

Fig. 1 illustrates the TDMR system based on a discrete Voronoi-grain model.[8] An input data sequence $x_k \in \{0,1\}$ with bit period T_x is encoded by an LDPC encoder and is mapped to a coded sequence $a_k \in \{\pm 1\}$, which will then be split into three adjacent tracks $\{a_{k,l-1}, a_{k,l}, a_{k,l+1}\}$ with track pitch T_z for recording onto a magnetic medium. In this paper, we consider the medium, approximately with the grain size of 4.6 nm diameter and the non-magnetic boundary of 0.9 nm.[8] Also, we employ the method (with same parameters) proposed by Yamashita *et al.*[8] to generate the TDMR readback signal, which is obtained by convolving the magnetization pattern of discrete Voronoi grains, $M(m, n)$, with the read-head sensitivity function, $\psi(m, n)$, where m and n are the time indices of the bit period in the along- and across-track directions, and then add a small amount of additive white Gaussian noise (AWGN) for the electronics noise.[5,8]

Then, the readback sequence, $r_{k,l}$, is equalized by a 2D equalizer[9] so as to shape the overall channel response to the 2D target.[9,10] Specifically, the kth equalizer output on the lth track can be expressed as

$$y_{k,l} = \underbrace{\sum_n \sum_m h_{m,n} a_{k-m,l-n}}_{s_{k,l}} + w_{k,l}, \tag{1}$$

where $a_{k,l}$'s are the recorded bits, $h_{m,n}$'s are the 2D target coefficients, $s_{k,l}$'s are the noiseless target outputs, and $w_{k,l}$ is the filtered noise.

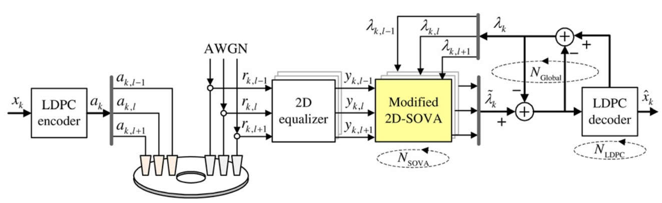

FIG. 1. A TDMR channel model with the proposed method.

[a)]Author to whom correspondence should be addressed. Electronic mail: piya@npru.ac.th

Next, each of the equalizer outputs $\{y_{k,l-1}, y_{k,l}, y_{k,l+1}\}$ is processed by a separate 2D-SOVA[11] detector to produce the soft outputs $\{\tilde{\lambda}_{k,l-1}, \tilde{\lambda}_{k,l}, \tilde{\lambda}_{k,l+1}\}$. The 2D-SOVA detectors exchange this soft information for N_{SOVA} times, before combining and sending the refined soft information to the LDPC decoder to produce the log-likelihood ratio (LLR) of bit a_k, λ_k. Thus, this LLR sequence will be split into three sequences $\{\lambda_{k,l-1}, \lambda_{k,l}, \lambda_{k,l+1}\}$ before feeding them back to each corresponding 2D-SOVA detector for the next global iteration.

III. PROPOSED SCHEME

To handle the 2D interference, we propose to exchange the soft information among all 2D-SOVA detectors as shown in Fig. 2, where the conventional 2D-SOVA detector is employed in the 1st SOVA iteration (i.e., $N_{\text{SOVA}} = 1$). However, the proposed method begins at the 2nd and higher SOVA iteration, where the lth detector exploits the sidetrack information from the $(l-1)$th and $(l+1)$th detectors, and the $(l-1)$th and $(l+1)$th detectors employ the sidetrack information only from the lth detector. Specifically, this sidetrack information is used to enhance the reliability of the *a priori* information before evaluating the branch metric in the 2D-SOVA detector for the next SOVA iteration.

To perform maximum-likelihood equalization via 2D-SOVA, we apply a technique introduced in the bidirectional SOVA[12] to compute the extrinsic information of the bit a_k, $\tilde{\lambda}_k$, for the LDPC decoder. Define (u, q) as the transition from stage u to stage q in the trellis diagram.[7] In practice, the conventional SOVA detector computes the kth branch metric on the lth track associated with (u, q) according to[7,12]

$$\gamma_{k,l}(u,q) \approx -\frac{1}{2\sigma^2}|y_{k,l} - s_{k,l}(u,q)|^2 + \ln(p_{k,l}(q|u)), \tag{2}$$

where σ^2 is the noise variance seen at the input of the SOVA detector, $s_{k,l}(u, q)$ is the kth target output on the lth track from Eq. (1) associated with (u, q), and $p_{k,l}(q|u)$ is the kth *a priori* probability on the lth track. Generally, the quality of the extrinsic information $\tilde{\lambda}_k$ depends on how good the branch metric $\gamma_{k,l}(u, q)$ is, which in turn helps reduce the ITI effect. In this paper, all 2D-SOVA detectors iteratively exchange the soft information so that a better $\gamma_{k,l}(u, q)$ can be obtained. To achieve this, we need to modify the branch metric calculation in Eq. (2) such that an improved $p_{k,l}(q|u)$ is included.

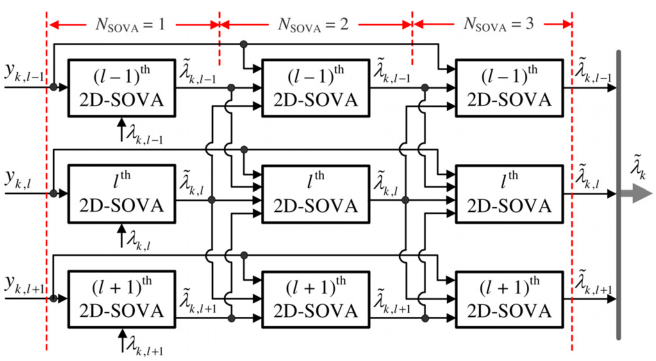

FIG. 2. The soft information exchange process at the modified 2D-SOVA detectors for $N_{\text{SOVA}} = 3$.

Consider the 3-by-3 asymmetric target,[10] whose trellis diagram has 64 states with 8 outgoing branches connected to 8 different states. Because each branch corresponds to the input data $[a_{k,l-1}, a_{k,l}, a_{k,l+1}]$, the *a priori* probability in Eq. (2) can then be calculated from

$$p_{k,l}(q|u) = p(a_{k,l-1})\,p(a_{k,l})\,p(a_{k,l+1}), \tag{3}$$

where $p(a_{k,l} = +1) = e^{\lambda_{k,l}}/(1 + e^{\lambda_{k,l}})$ and $p(a_{k,l} = -1) = 1 - p(a_{k,l} = +1)$. Note that when the sidetrack information is used to compute $p_{k,l}(q|u)$, the $\lambda_{k,l}$ will be replaced by the 2D-SOVA output, $\tilde{\lambda}_{k,l}$.

To reduce the complexity, we employ the 3-by-3 symmetric 2D target[10] in this paper, whose trellis diagram has 36 states with 6 outgoing branches connected to 6 different states because the upper and the lower target coefficients are the same. In this case, it can be shown that the $p_{k,l}(q|u)$ in Eq. (3) can be computed as $p_{k,l}(q|u) = p(a_{k,l})p(b_{k,l})$, where $b_{k,l} = a_{k,l-1} + a_{k,l+1}$, and

$$p(b_{k,l}) = \begin{cases} p(a_{k,l-1} = -1)\,p(a_{k,l+1} = -1), & b_{k,l} = -2 \\ p(a_{k,l-1} = +1)\,p(a_{k,l+1} = +1), & b_{k,l} = +2 \\ p(a_{k,l-1} = -1)\,p(a_{k,l+1} = +1) \\ +p(a_{k,l-1} = +1)\,p(a_{k,l+1} = -1), & b_{k,l} = 0. \end{cases} \tag{4}$$

IV. SIMULATION RESULTS

Consider a rate-8/9 coded system in which each block of 3640 message bits is encoded by a regular (3, 27) LDPC encoder, resulting in a 4095-bit block sector. The parity-check matrix has 3 ones on each column and 27 ones on each row. This paper defines the signal-to-noise ratio (SNR) as $20\log_{10}(A/\sigma_S)$, where A assumed to be 1 is the saturation level of an isolated waveform calculated by using the ideal granular medium[8] and σ_S is the standard deviation of AWGN. The 2D 3-by-3 symmetric target and its corresponding 2D 3-by-7 equalizer are designed based on a minimum mean-squared error approach.[9,10] In simulation, $N_{\text{SOVA}} = 3$ and $\sigma = \sigma_S$ are used, and the LDPC decoder is implemented based on the message passing algorithm[6] with $N_{\text{LDPC}} = 10$ internal iterations.

We make a comparison among (1) the conventional receiver denoted as "Conv" and three conventional 2D-SOVA detectors (i.e., $N_{\text{SOVA}} = 1$) are used, (2) the PIMM,[2] and (3) the proposed scheme, where all schemes have random data on the $(l-2)$th and $(l+2)$th tracks. Fig. 3(a) shows the BER

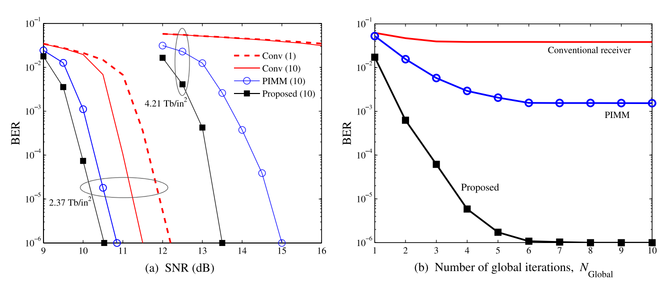

FIG. 3. Performance comparison (a) with different ADs and (b) as a function of N_{Global}'s at 4.21 Tb/in^2 and SNR = 13.5 dB.

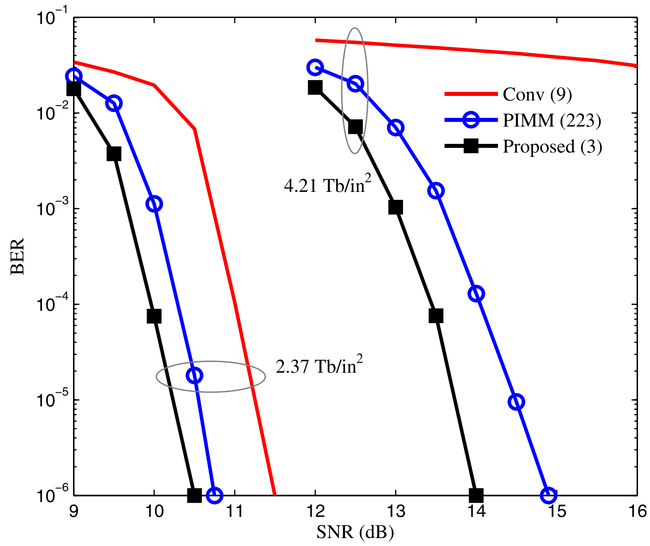

FIG. 4. Performance comparison with same complexity.

performance of different schemes at the AD of 2.37 Tb/in^2 ($T_x = T_z = 16.5$ nm) and 4.21 Tb/in^2 ($T_x = T_z = 12.375$ nm). Notice that the number inside the parenthesis in Fig. 3(a) indicates the total number of global iterations, N_{Global}, used to generate each curve. Apparently, the proposed scheme performs better than the others, especially when AD is increased. For example, at 4.21 Tb/in^2, the proposed scheme is far superior to the conventional receiver and is better than the PIMM by about 1.5 dB at BER $= 10^{-6}$. Fig. 3(b) also shows the BER performance as a function of N_{Global}'s at AD of 4.21 Tb/in^2 and SNR $= 13.5$ dB. It is clear that the proposed scheme performs the best and no performance gain is obtained for all schemes after $N_{\text{Global}} = 6$.

Additionally, we also compare the performance of all schemes when they have same complexity. To do so, we define the complexity as the total number of multiplications (per bit), including the LDPC decoder. Note that only multiplication is considered because it has much more complexity than addition in terms of circuit implementation. With carefully counting the number of operations, it can be shown that the conventional receiver, the PIMM, and the proposed scheme have 1081 N_{Global}, 44 N_{Global}, and 3274 N_{Global} multiplications, respectively. Here, we assume that current technology can support the total number of multiplications equal to 3 iterations of the proposed scheme, which is approximately equal to 9 and 223 iterations of the conventional receiver and the PIMM, respectively. Fig. 4 compares the performance of different schemes when they have same complexity. It is evident that the proposed scheme still performs better than other schemes, especially at high AD. This might be because the proposed scheme can combat the severe ITI as opposed to the other schemes.

V. CONCLUSION

This paper proposes an iterative ITI mitigating method to combat the severe 2D interference in TDMR systems, which employs three modified 2D-SOVA detectors in conjunction with an iterative processing technique. Specifically, the three modified 2D-SOVA detectors exchange soft information to improve the reliability of the *a priori* information and use it in the branch metric calculation, before passing the refined soft information to the LDPC decoder. Simulation results indicate that the proposed scheme performs better than both the conventional receiver and the PIMM, especially when AD is high. Therefore, the proposed scheme is worth employing in the system that experiences the severe 2D interference (e.g., TDMR and bit-patterned media recording).

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[1]R. Wood *et al.*, IEEE Trans. Magn. **45**, 917 (2009).
[2]L. M. M. Lyint *et al.*, IEEE Trans. Magn. **45**, 3691 (2009).
[3]Y. Okamoto *et al.*, IEEE Trans. Magn. **47**, 3570 (2011).
[4]W. Chang and J. R. Cruz, IEEE Trans. Magn. **46**, 3899 (2010).
[5]R. M. Todd *et al.*, IEEE Trans. Magn. **48**, 4594 (2012).
[6]R. Gallager, IRE Trans. Inf. Theory **8**, 21 (1962).
[7]J. Hagenauer and P. Hoeher, in *Proceedings of IEEE Globecom'89* (Dallas, Texas, 1989), p. 1680.
[8]M. Yamashita *et al.*, IEEE Trans. Magn. **47**, 3558 (2011).
[9]S. Nabavi and B. V. K. Vijaya Kumar, in *Proceedings of ICC'07* (Glasgow, 2007), p. 6249.
[10]S. Karakulak *et al.*, IEEE Trans. Magn. **46**, 3639 (2010).
[11]S. Koonkarnkhai *et al.*, Procedia Eng. **32**, 323 (2012).
[12]B. Vucetic and J. Yuan, *Turbo Codes: Principles and Applications*, 2nd ed. (Kluwer, Norwell, MA, 2000).