Three-Track Detection Using a Multi-Layer Perceptron for Dual-Layer Bit-Patterned Magnetic Recording Systems

Santi Koonkarnkhai[1], *Member, IEEE*, Siriphon Plotchu[1], Warunee Martnok[1], Natthakan Rueangnetr[2], Sathapath Kilaso[3], Piya Kovintavewat[1], *Senior Member, IEEE*, and Chanon Warisarn[2], *Member, IEEE*
[1]Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakhon Pathom, Thailand
[2]School of Integrated Innovation Technology, King Mongkut's Institute of Technology Ladkrabang, Bangkok, Thailand
[3]College of Innovation and Management, Suan Sunandha Rajabhat University, Bangkok, Thailand

This paper proposes a multi-layer perceptron (MLP)-based three-track detection method for dual-layer bit-patterned magnetic recording systems. Three architectures are explored: one MLP for three tracks, two MLPs for upper and lower layers, and three individual MLPs per track. Simulation results show that all MLP-based methods outperform conventional partial response maximum likelihood detection, especially under high areal density and complex interference. Among them, the two-MLP system achieves the best bit-error rate performance by effectively separating detection tasks across layers.

***Index Terms*—Dual-layer magnetic recording, multi-layer perceptron, multi-track detection, three dimensional interference**

I. INTRODUCTION

TRADITIONALLY, hard disk drives use single-layer magnetic recording. Recent studies, however, have proposed dual-layer magnetic recording (DLMR) systems to significantly increase areal density (AD), potentially reaching 10 Tb/in^2, as targeted by the Advanced Storage Research Consortium (ASRC) [1]. Designing the writing, reading, and signal processing systems for DLMR encounters major challenges due to increased complexity and data density if compared to a single-layer magnetic recording system.

One of the main challenges that DLMR faces the three dimensional (3D) interference, consisting of inter-symbol interference (ISI), inter-track interference (ITI), and inter-layer interference (ILI). If these interferences are not effectively managed, they can result in a high error rate during a data detection process. In addition to the 3D interference, DLMR also encounters other unwanted issues, such as track mis-registration (TMR) and media noise.

Several studies have addressed the interference mitigation in DLMR. Luo *et al.* [2] combined PRML detection with a neural network (NN) to manage bit-cell misalignment. Given that the interference often exhibits nonlinear characteristics, NNs have been applied effectively, including iterative decoding approaches proposed by Jeong and Lee [3] and ITI mitigation by Koonkarnkhai *et al.* [4].

This paper introduces a multi-layer perceptron (MLP)-based 2-head 3-track (2H3T) detection method for a dual-layer BPMR system, whose objectives are to develop MLP architectures capable of detecting data across three tracks.

II. A CHANNEL MODEL FOR DUAL-LAYER BPMR

Fig. 2 shows a dual-layer BPMR system employing 2H3T detection, where $\{a_{j,k}\} \in \{\pm 1\}$ is a binary user bit sequence of the j-th track at k-th bit. Note that if j is an odd number, it refers to a track in the 1-st recording layer, whereas if j is an even number, it refers to a track in the 2-nd recording layer.

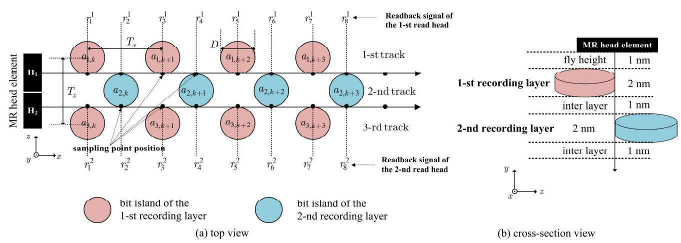

Fig. 1. The geometry of dual-layer BPMR medium, (a) top view and (b) cross-section view under the total AD of 4.0 Tb/in^2.

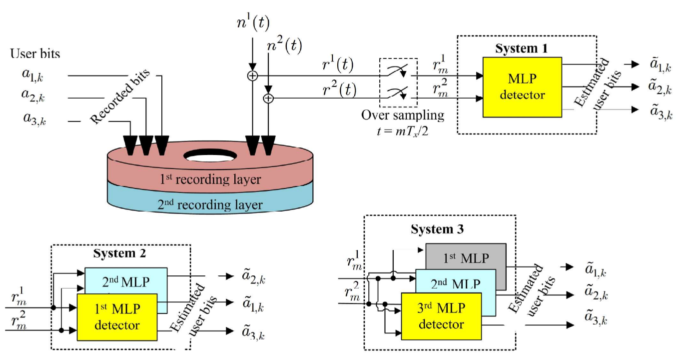

Fig. 2. A dual-layer BPMR system with the proposed MLP-based 2H3T detection methods.

This paper assumes that each recording layer has a thickness of 2 nm, and the isolation layer separating the two recording layers has a thickness of 1 nm, as depicted in Fig. 1(b). Each readback signal can be modeled as the output of two dimensional convolution between the magnetization of the bit-patterned medium and the read head sensitivity response. Thus, the readback signal of the q-th read head where $q \in \{1, 2\}$ can be expressed as

$$r^q(x,t) = \sum_{l=q}^{q+1} \iint_S m_l(\xi,\eta)\, h_l(x-\xi, t-\eta)\, d\xi\, d\eta + n^q(t), \quad (1)$$

where $m_j(\xi, \eta)$ denotes the magnetization at position (ξ, η) in the down- and cross-track directions of the j-th track, $h_j(x, z)$ represents the read head sensitivity response of the j-th track, and $n^q(t)$ is additive white Gaussian noise of the q-th read head with with two-sided power spectral density $N_0/2$.

At the conventional receiver, the readback signal $r^q(t)$ are oversampled a time $t = mT_x/2$ to obtain the sequence $\{r_m^q\}$. The sampled sequences $\{r_m^q\}$ are then fed to 1D equalizers and the 2D Viterbi detectors to obtain the estimated input bit sequences $\{\tilde{a}_{j,k}\}$, according to the PRML technique [5]. Nonetheless, in the presence of ultra-high ADs and multi-dimensional interference, PRML cannot perform reliably. Consequently, this paper proposes using an MLP-based detection approach to replace traditional PRML detection, aiming to improve data detection accuracy under more complex conditions.

III. Proposed MLP-Based Detection

Fig. 2 shows three proposed MLP-based data detection architectures. Specifically, System 1 uses a single MLP to detect all three tracks simultaneously; System 2 employs two MLPs, with the first detecting two upper-layer tracks and the second detecting the lower-layer track; and System 3 uses three independent MLPs, each dedicated to a single track.

All MLPs are configured with identical parameters, comprising one input layer and five hidden layers. Additionally, System 1 uses one MLP with three output nodes to detect all tracks simultaneously. System 2 employs two MLPs: one with two outputs for the upper tracks and another with one for the lower track. System 3 uses three separate MLPs, each dedicated to detecting a single track. All systems leverage inter-track correlation learning to improve detection performance.

All systems are trained using the Adam optimizer with a learning rate of 0.001 on 1000 4096-bit sectors without TMR or media noise to assess baseline performance under ideal condition. Extensive simulation searches identify that the optimal MLP architecture composes of five hidden layers with 128, 64, 32, 16, and 8 nodes, respectively, and utilizes the hyperbolic tangent activation function for best performance. Also, an input layer with 8 nodes provides the highest detection accuracy and system efficiency (data not shown).

IV. Simulation Result

This paper defines a signal-to-noise ratio as $\text{SNR} = 10\log_{10}\left(A^2/\sigma^2\right)$ in dB, where $A = 1$ is the normalized peak amplitude of the readback signal, and σ^2 represents the noise power. A performance comparison is conducted among different systems at an AD of 4 Tb/in^2, including the three proposed systems as shown in Fig. 2 and the conventional system, which utilizes a PRML-based detection scheme consisting of a 7-tap 1D equalizer and a 2D Viterbi detector.

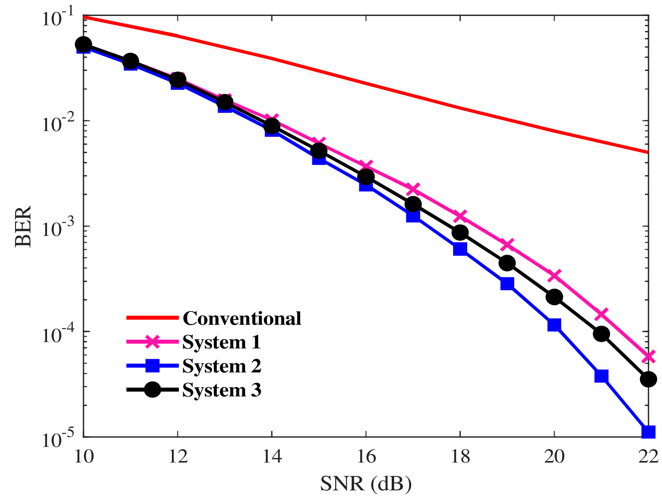

Fig. 3. Performance comparison for different systems.

Fig. 3 compares the performance of different systems. It is apparent that all proposed systems are superior to the conventional approach in terms of bit error rate (BER). Specifically, System 2 demonstrates the best performance, followed by System 3 and System 1, respectively. This may be attributed to System 2's ability to effectively separate data detection across two recording layers. Specifically, the first MLP processes data from the two upper tracks, which carry stronger signals, while the second MLP handles data from the lower layer. This separation reduces data complexity, improves learning accuracy, and enables the model to better capture the distinct characteristics of each layer. In contrast, System 1 employs a single MLP for all three tracks, which increases the likelihood of errors, whereas System 3 assigns a separate MLP to each track, which is more susceptible to overfitting.

V. Conclusion

This paper proposes an MLP-based three-track detection approach for dual-layer BPMR systems. Three architectures are evaluated, namely, a single MLP for all tracks, two MLPs for the upper and lower layers, and three separate MLPs for each track. Simulation results demonstrate that all MLP-based systems significantly outperform the conventional PRML detection, with the two-MLP architecture achieving the lowest BER by effectively partitioning the detection tasks between the layers.

Acknowledgments

This project is funded by School of Integrated Innovative Technology (SiiTEC), grant number 2568-02-10-003, King Mongkut's Institute of Technology Ladkrabang, Thailand.

References

[1] E. Roddick, M. Kief, and A. Takeo, "A new advanced storage research consortium HDD technology roadmap," in *Proc. of IEEE 33rd Magn. Recording Conf. (TMRC)*, Milpitas, CA, USA, Aug. 2022, pp. 1-2.

[2] K. Luo, Y. Liao, K. Zhang, Y. Jian, S. Wang, J. Chen, and P. Lu,"On the impact of interlayer misalignment for dual-layer data detection in three dimensional magnetic recording," *J. Magn. Magn. Mater.,* vol. 610, pp. 172522, Nov. 2024.

[3] S. Jeong and J. Lee. "Iterative signal detection scheme using multilayer perceptron for a bit-patterned media recording system," *Appl. Sci.,* vol. 10, no. 10, 2020.

[4] S. Koonkarnkhai, P. Kovintavewat, and C. Warisarn, "An MLP-based ITI suppression method for multi-head multi-track bit-patterned magnetic recording," *IEEE Trans. Magn.,* 2025. doi:10.1109/TMAG.2025.3542387

[5] J. Moon and W. Zeng, "Equalization for maximum likelihood detector," *IEEE Trans. Magn.,* vol. 31, no. 2, pp. 1083 – 1088, Mar. 1995.