A Partial Response Maximum Likelihood Detection Using Modified Viterbi Decoder for Asymmetric Optical Storage Channels

Kyusuk Lee* ***Associate Members***, Joohyun Lee*, Jaejin Lee* ***Regular Members***

ABSTRACT

We propose an improved partial response maximum likelihood (PRML) detector with the branch value compensation of Viterbi decoder for asymmetric high-density optical channel. Since the compensation value calculated by a survival path is applied to each branch metric, it reduces the detection errors by the asymmetric channel. The proposed PRML detection scheme improves the detection performance on the 2^{nd}, 3^{rd} and 4^{th} order PR targets for asymmetric optical recording channel.

Key Words : PRML, Viterbi decoder, optical storage, asymmetric channel, 17PP code

I. Introduction

Modulation codes are used to improve the performance of the system by matching the characteristics of the recorded signals to the channel. There are many types of modulation codes according to the channel condition. In the optical recording system, (d, k) run-length-limited (RLL) code is mostly employed as the modulation code. The (d, k) RLL code has constraints, which the run of "0" symbols between consecutive "1" symbols must be at least d and no more than k[1]. In the recording system, "1" symbol means the transition of the signal and "0" symbol maintains the previous signal level. This method is called NRZI (non-return-to-zero-inverse). By this reason, as the minimum constraint length, d guarantees the minimum space between transitions, and the inter-symbol interference (ISI) can be reduced. The maximum constraint length, k also controls the timing recovery. An example of (1, 7) RLL code is followed by

$$\cdots\ 0010010100000001000100\ \cdots$$

As shown in the example, data patterns such as '0110', '1011', etc. are not appeared because constrained data sequences are generated by the modulation coding rule. Thus, each data pattern has different event probability according to the modulation code.

Generally, the peak detection method has been used to detect binary bits from the read-back signal of the optical recording system. However, there is limitation to improve the detection performance because of the ISI as the recording density increases. To solve this problem, partial response maximum likelihood (PRML) detection has been proposed in the high-density optical recording system. But, the conventional PRML has some troubles to be applied at the optical recording system. The conventional method assumes that all branch metrics (BMs) have the same event probabilities[2]. As stated above, each data pattern has different event probability due to the RLL modulation code. Thus, this supposition is not true. Also, the signal from the disc is easy to distort by the media noise, asymmetry and tilt in the high-density optical channel. Therefore, the

* Telecommunication and Information Storage Lab., Department of Electronic Engineering, Dongguk University(zlee@dongguk.edu)
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conventional PRML detection schemes are difficult to resolve the performance degradation[3].

We propose a PRML detection with modified BM calculation method in Viterbi trellis. We can be ambiguous selecting one BM out of two BMs entered the state by ISI or noises. In this case, as applying previously calculated event probabilities of BM, it can compensate the BM values for the next equalized data. This method improves the detection performance by reducing an incorrect selection for the survival path. In this paper, we show that the detection performance has been improved on the 2nd, 3rd and 4th order PR targets for high-density optical channel model. The computer simulation condition is considered in AWGN and asymmetry channel.

In Section II, we explain the algorithm of the proposed PRML detection method. Section III shows the simulation results, and conclusion is drawn in Section IV.

Ⅱ. Design of Modified PRML Detection Method

2.1 Branch metric calculation

A survival path selects one BM that has the minimum sum of previous path metric (PM) and BM between two BMs. As shown in Fig. 1, let the PM_a and PM_d be the PMs of the states S_a and S_d, respectively, and the BM_{ab} and BM_{db} be the two branch metrics entering the state S_b. If the BMs and PMs are given by

$$PM_a + BM_{ab} > PM_d + BM_{db} \qquad (1)$$

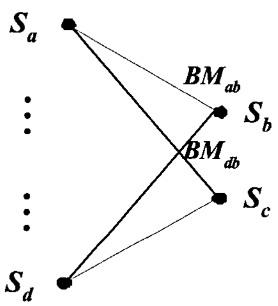

Fig. 1. A Part of Viterbi trellis

Table 1. The probability of the 17PP coded sequence on the 3rd order PR target

Data Pattern	Probability
−1 −1 −1 −1	0.55314
−1 −1 −1 +1	0.44686
+1 −1 −1 −1	0.62287
+1 −1 −1 +1	0.37723
−1 +1 −1 −1	0.00000
−1 +1 −1 +1	0.00000
+1 +1 −1 −1	1.00000
+1 +1 −1 +1	0.00000
−1 −1 +1 −1	0.00000
−1 −1 +1 +1	1.00000
+1 −1 +1 −1	0.00000
+1 −1 +1 +1	0.00000
−1 +1 +1 −1	0.37786
−1 +1 +1 +1	0.62214
+1 +1 +1 −1	0.44633
+1 +1 +1 +1	0.55367

then the survival path becomes the branch BM_{db} by assuming that the event probabilities of BM_{ab} and BM_{db} are equal. However, this is not always true. The 17PP modulation code for the Blu-ray Disc (BD) is an (1, 7) RLL code. Therefore, several data patterns do not appear or appear more frequently because of the constraints and the asymmetric channel characteristic. Table 1 shows the event probabilities of each data pattern on the 3rd order PR target. They are calculated by computer simulation. This data expresses signal levels such as "-1" and "+1" by NRZI method. With the 17PP modulation coded sequence, we have counted the frequency for each pattern. The data '-1-1-1-1' and '-1-1-1+1' enter the same state and their event probabilities are 0.55314 and 0.44686, and the sum is 1. From this table, we can confirm that the event probabilities of each data pattern are not same. It means that the selected frequency of each BM is also different. Thus, this method can be wrong in the Vierbi trellis by assuming equal probability.

In this paper, we propose the new BM calculation method. We can get the event probability of each BM as cumulating the number of survival paths through the procedure of detecting bits. In

Fig.1, if total selected times of BM_{ab} is c_{ab} and total number of detecting bits is N, the event probability of BM_{ab} is followed by

$$p_{ab} = c_{ab}/N \tag{2}$$

In the result, the PM is calculated by

$$tPM_{ab} = (1 - p_{ab}) \cdot BM_{ab} + PM_a \tag{3}$$

$$tPM_{db} = p_{ab} \cdot BM_{db} + PM_d \tag{4}$$

$$PM_b = \min(tPM_{ab}, tPM_{db}) \tag{5}$$

where tPM_{ab} and tPM_{db} are temporary PMs for the comparison. In conventional ML, tPM_{db} is selected as PM_b if the result is like the equation (1). But, if the difference of tPM_{ab} and tPM_{db} is very small or equal by ISI or noise, we cannot ensure correct path of two BMs. In this case, if BM_{ab} had been selected more than BM_{db} previously, we decide BM_{ab} as survival path. Therefore, when we use the probability as the compensation value, we multiply it on the contrary to the other BM as equation (2) and (3) in order that the BM with larger event probability can be selected.

2.2 Modified PRML detection scheme

Fig. 2 shows the modified process of the BM and PM calculation for the 3rd order PR target. Each BM is calculated with the equalizer output symbol, and then the BMs are multiplied by the

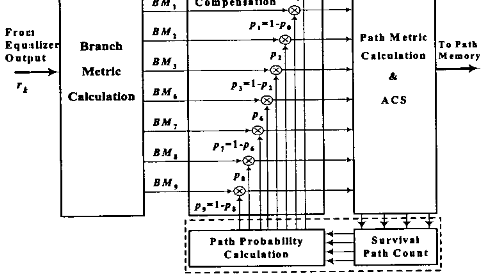

Fig. 2. The modified process of the branch metric and path metric calculation

compensation values of the paths before the PM calculation. Several branches are deleted from the trellis because the minimum constraint length of the sequence is 1. In Table 1, the probability zero means that the branch is deleted. So, Fig. 2 shows that six out of sixteen branches are deleted on the 3rd order PR target.

The probability calculation process is as follows. First, the add-compare-select (ACS) block selects the survival path, and then the number of times selected is cumulated in the survival path count block. Second, in the path probability calculator, the probability of each BM is calculated. Third, the probability is applied to each BM as the compensation value when the next PM is calculated. This process occurs at every time and renews the probability continuously in order to adapt for the asymmetric channel characteristic.

Ⅲ. Simulation Results

3.1 Channel model

For the simulation, we use the 17PP modulation code[4] and the high-density optical channel model[5] that is similar to the 27GB optical disc. The asymmetric impulse response, $h(t)$, of optical recording channel model used for evaluating the performance of the proposed PRML detection is given by

$$h(t) = \frac{2}{ST\sqrt{\pi}} \exp\left[-\left(\frac{2(t-\alpha)}{ST}\right)^2\right] \tag{6}$$

where a ($0 \le a \le 1$), S and T are asymmetric parameter, normalized density and symbol duration, respectively. The performance of the PRML detections are examined at S=4.5. The impulse response of the channel is designed to have the asymmetry of 15% (a = 0.15), and we measure the performance of three targets such as PR(121), PR(1221) and PR(12221).

3.2 Simulation results

Table 2 shows the probabilities of the conventional and proposed PRMLs' BMs on the PR(121)

Table 2. The Probability of BMs at the 10^4th and 10^5th bits for the conventional and the proposed PRML Detections

Branch Metric	Conventional PR(121) Target		Proposed PR(121) Target	
	10^4th bits	10^5th bits	10^4th bits	10^5th bits
BM0	0.4972	0.4971	0.5189	0.5225
BM1	0.5027	0.5029	0.4811	0.4775
BM2	1.0000	1.0000	1.0000	1.0000
BM3	0.0000	0.0000	0.0000	0.0000
BM4	0.0000	0.0000	0.0000	0.0000
BM5	1.0000	1.0000	1.0000	1.0000
BM6	0.5019	0.5019	0.4797	0.4766
BM7	0.4980	0.4980	0.5203	0.5234

target. The probabilities at the 10^4th and 10^5th bits have no change on the conventional PRML, but on the other hand there are many differences on the proposed PRML. Fig. 3 presents the trellis diagram that the compensation is applied to the PR(121) target. At the 10^4th bit, the probabilities of six BMs are 0.5189, 0.4811, 1.0, 1.0, 0.4797 and 0.5203. At the next bit, the probabilities have almost no change. But, at the 10^5th bit, they are 0.5225, 0.4775, 1.0, 1.0, 0.4776 and 0.5234. Thus, four branches are different because the survival paths are changed according to the situation at every bit.

In the results, as shown in Fig. 4, we can notice that the performance of the PR(121)ML detection with the branch value compensation is improved by about 2dB compared with that of the conventional PR(121)ML detection at 10^{-5} bit error rate (BER). For the proposed PR(1221)ML and PR(12221)ML methods, their SNR performances are improved by about 1dB compared with those of conventional methods at 10^{-5} BER.

IV. Conclusion

In this paper, we have proposed the modified PRML that can improves the detection performance in the asymmetric high-density optical channel. It is a new BM calculation method applying the compensation value using the event probability of each BM. From the computer simulation on the 2^{nd}, 3^{rd} and 4^{th} order PR targets for asymmetric optical channel model, the performances of all PR targets are improved by over 1dB compared with those of conventional PRML detection at 10^{-5} BER. Therefore, the proposed method can easily adapt for the asymmetric channel characteristic and decrease the incorrect decision of the survival path selection.

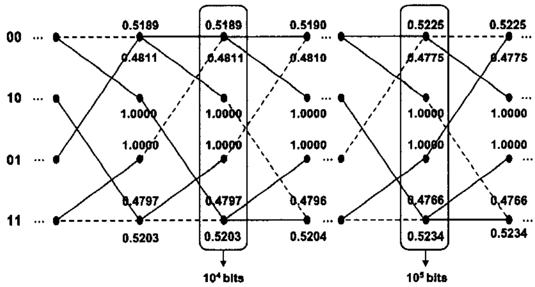

Fig. 3. The trellis diagram that it is applied the compensation value calculated by probability of branch metric on the PR(121) target

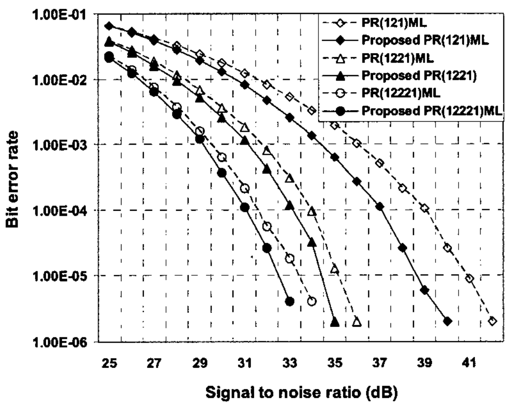

Fig. 4. BER comparisons of several PRMLs

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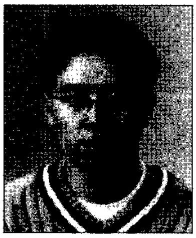
Kyusuk Lee **_Associated member_**

Feb. 2004 B.S. degree in electronics engineering from Dongguk University.

Mar. 2004~ M.S. candidate in electronics engineering from Dongguk University.

<Research interests> Channel coding, detection algorithm, modulation code.

Joohyun Lee **_Regular member_**



Feb. 2000 B.S. degree in electronics engineering from Dongguk University.

Feb. 2002 M.S. degree in electronics engineering from Dong-guk University.

Aug. 2005 Ph. D. degree in electronics engineering from Dongguk University.

<Research interests> Channel coding, detection algorithm, perpendicular magnetic system.

Jaejin Lee **_Regular member_**

Feb. 1983 B.S. degree in electronics engineering from Yonsei University.

Dec. 1984 : M.S.E.E degree in electrical engineering from University of Michigan.

Dec. 1994 : Ph. D. degree in electrical engineering from Georgia Institute of Technology.

Jan. 1995~Dec. 1995 Research associate in Georgia Tech.

Jan. 1996~Feb. 1997 Research staff in Hyundai Electronics

Mar. 1997~ Professor, Dept. of Electronic Engineering, Dongguk University.

<Research interests> Channel coding, storage system, communication theory.