Error-Correction codes For Optical Disc Storage

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ABSTRACT

From CD to DVD to Blu-ray Disc, that optical disc all adopted the error-correction code to improve the storage. The error-correction code for the Blu-ray Disc, the up-to-the-minute optical disc, is more advanced than others. Many new technologies are applied in the Blu-ray Disc, especial the error-correction code which called Picket code is more powerful than RS and RSPC code. In the same condition, the error-code rate of the optical disc which used the Picket code is 1.5×10^{-18}, and the optical disc used RSPC is 5.7×10^{-7}.

In this paper, the characteristic of those technologies which used in the optical disc will be discussed, include RS code used in CD system, RSPC code used in DVD system, and Picket code. Finally, it will add two different error matrixes to simulate the process of the error-correction code for the DVD system. In this simulating process, especially, we will compare the RS and RSPC code from mathematical direction in the simulation which is different from the professional comparison, this method can be easily accepted by beginner and the comparative result is very intuitionistic for freshman.

Keywords: ECC code, optical disc storage, DVD system, Blu-ray Disc, mathematical simulation

INSTRUCTION

In general, the optical disk is subject to various factors, such as noise, distortion, and interference, at the same time, there is a massive amount of digital data stored in optical disk storage. Therefore, the number of the errors in optical disk storage may be enormously, the probability of the errors also is increase because of those factors. [1, 2]

Usually, the error in optical disc storage can be divided two types. One is random error, another is burst error. As regard to optical disc storage, we can find that single errors are caused by noise in combination with other sources of signal deterioration such as tilt of the disc or defocus of the laser spot on the disc. They are called single errors because they only affect one or two bytes. And we know digital signals can be converted by pits recorded on CDs. So those single errors occur when system is reading those pits are generally caused by scratches on the CD from mastering or production, by scratches from normal use, and so on. On the other hand, burst errors are caused by defects on the disc surface like scratches, dust fingerprints, servo or synchronization signal problems etc. [4]

In order to correct the corrupted data, an original information sequence is transformed by error control coding. In general, the original information sequence formed the code words which contain original data bytes and appended redundant data bytes. Those redundant data bytes which are written onto the optical disk and are used are used to recover the original data information.

General speaking, when messages have to be sent over (or temporarily stored in) a channel (or medium), the error correct codes make a great function. [3]

Therefore a error-correction system must have this two kinds of abilities: 1) High random error correct ability, 2) Long burst error correct ability.

CIRC FOR COMPACT DISC

The earlier error-correction code was used in the digital audio disc, and this agreement was achieved by N. V. Philips of Netherlands discussed with Sony Corp. of Japan over several years, this is famous Cross Interleave Reed Solomon Code (CIRC).

CIRC synthesizes the interleaving technology、the cross-interleaving technology、the delayed interleaving technology and RS technology, which can not only correct the random error, but also the burst error.

In CD system, CIRC makes use of two Reed Solomon codes, the first one, which we will denote by C_1 has $n_1 = 32$, $k_1 = 28$ and $s = 8$,, the second one, referred to as C_2 has $n_2 = 28$, $k_2 = 24$ and $s = 8$. Since both codes have $n - k = 4$, their minimum distance are 5, which may be used for either 2 error correction, 4 erasure correction, or some other combined strategy. [1]

One frame is formed by 24 bytes increments when data is input into the Reed-Solomon encoder. Firstly, data is

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entered into the scrambler, and it will be delayed two frames. Then 4 bytes of parity is added in the C_2 encoder prior to inputting the data into the interleave circuit where 108 frames are interleaved. In this step, the burst errors are converted to random errors by interleaving. After interleaving, the data are sent into the C_1 encoder, and 28 bytes of data and 4 bytes of parity are added on the data. Finally the parity will be inverted and odd frame is delayed according to order. [4]

The correct maximum fully correctable burst length of CIRC is up to 4000 bits (2.5mm). After CIRC, the error-code rate is less than 10^{-9}, which is enough for Compact disc. But for CD-ROM, it will conduce to an unexpected result for computer system, so the standard of CD-ROM had added the EDC (Error Detection Code) and ECC (Error Correction Code) in every sector which can correct the error that CIRC can not correct. This method can make the error-code rate is less than 10^{-13} which satisfy the requirement of CD-ROM. [1, 2]

RSPC FOR DVD

In 1993, Toshiba made history by introducing DVD technology to the industry. Toshiba provided leadership in building DVD alliance and cooperation with many companies in the development of unified DVD format and key enabling technologies. DVD provides a powerful shift in quality, interactivity and versatility when compared to traditional media.

As we all know, CIRC which Compact Disc has adopted is regard data as a successive data stream, and this is a kind of linear error-correction system. However, it is different from RSPC (Reed Solomon Product Code) which is adopted by DVD. RSPC treats data as block or array. Though it need twice buffer storage as CD, the efficiency is decuple to CD. CIRC can correct about 500 bits successive error, whereas RSPC can correct about 2800 bits.

The data on a DVD disc are organised as sectors of 2048 bytes plus 12 bytes of header data (see Fig.1) [1]. Blocks of 16 sectors are error protected using RSPC, which is block oriented and is more suitable for re-writable discs (with packet writing) than CIRC, which does not use a block format. The PI and PO data are parity bytes calculated horizontally and vertically over the data bytes.

As illustrated in Fig.1, each frame of the product code containing 192×172B of user data is encoded into 208×182B of coded data, by a (182, 172, 11) RS code in the row direction which called Inner Parity (PI) and a (208, 192, 17) RS code in the column direction which called Outer Parity (PO), here 182 refers to its length(measured in bytes), 172 refers to the number of encoded data bytes, and 11 refers to the minimum distance of the RS code. A (N,K) RS code contains K message symbols and N-K parity checking symbols, and is capable of correcting up to(N-K)/2 symbol errors. For (182,172) and (208,192) RS codes, each symbol is one byte.

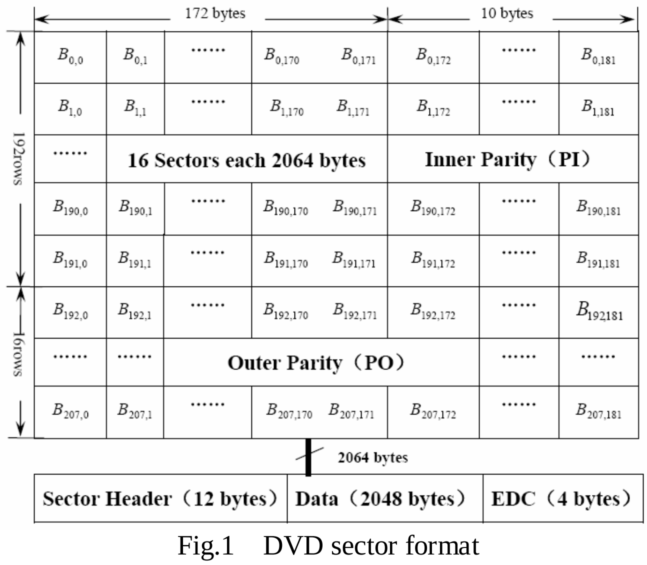

Fig.1 DVD sector format

In order to produce PO and PI in Fig.1, we must process following steps:

Firstly, in j ($j = 0 \sim 171$) column will add $B_{i,j}$ ($i = 192 \sim 207$) which is defined by the appending polynomial $R_j(X)$ to form the Outer Parity, here $B_{i,j}$ is 16 bytes.

$$R_j(x) = \sum_{i=192}^{207} B_{i,j} \cdot x^{207-i} = \{I_j(x) \cdot x^{16}\} \bmod \{G_{PO}(x)\}$$

In the equation

$$I_j(x) = \sum_{i=0}^{191} B_{i,j} \cdot x^{191-i}$$

$$G_{PO}(x) = \prod_{k=0}^{15} (x + \alpha^k)$$

Secondly, in $i\,(i = 0 \sim 171)$ row will add $B_{i,j}$ $(j = 172 \sim 181)$which is defined by the appending polynomial $R_i(X)$ to form the Inner Parity, here $B_{i,j}$ is 10bytes.

$$R_i(x) = \sum_{i=172}^{181} B_{i,j} \cdot x^{181-i} = \{I_i(x) \cdot x^{10}\} \bmod \{G_{PI}(x)\}$$

In the equation

$$I_i(x) = \sum_{j=0}^{171} B_{i,j} \cdot x^{171-j}$$

$$G_{PI}(x) = \prod_{k=0}^{9} (x + \alpha^k)$$

In the equation, α is the syndrome element of $P(x)$ which is the syndrome polynomial

$$P(x) = x^8 + x^4 + x^3 + x^2 + 1$$

As for DVD system, the decoder chip contains two frame buffer controllers which are a (182,172) row RS decoder and a (208,192) column RS decoder. The RS decoder will work out error locations and error values, and this information will be sent to the frame buffer controllers to update the frame buffer content. The architecture of decoder had minimized the amount of frame buffer access and timing constraint on the RS decoders. The product code word is stored row by row on disc. Therefore, bursts of errors have an orientation in the direction of rows.

To sum up, we can find that the most popular decoder architecture today can be summarized into four steps: 1) calculating the syndromes from the received codeword; 2) computing the error locator polynomial and the error evaluator polynomial; 3) finding the error locations; and 4)computing error values. [1, 2]

PICKET CODE FOR BLU-RAY DISC

Nowadays, there are several kinds of Blue-ray disc standard because of the agreement is not achieved by the big manufacturers and the program providers. Those kinds of standard are: 1) the standard of Blu-ray Disc by Sony and Philips; 2) the standard of AOD (Advanced Optical Disc) by Toshiba and NEC; 3) the standard of HD-DVD; 4) the standard of (UDO Ultra Density Optical) by Plasmon. Because the stand of Blu-ray Disc is brought forward earlier, so this paper will discuss the standard of Blu-ray Disc.

CeBIT 2004，a famous communication and correspond technology exposition, had show the most advanced technology and production in electronic area. In this exposition, SONY had show the Blu-ray disc recorder and correlative productions which will be sold in the Japan; and NEC, the competitor of SONY, had show another advanced disc-HD DVD disc. During the demonstration, the image of HDTV is transmitted by WMV9 code, and after that the image will be sent to PC to play. The quality of image is in this two kinds of disc are better than DVD in popular.

Now, we will make an investigation on the Blu-ray disc. Because of the fairly small spot, Blu-ray Disc, a thin cover layer and the high numerical aperture, is more sensitive to burst error than the DVD system.[12, 13] Foe example, the same defect on a Blu-ray Disc will influence more data bits than on a DVD Disc. Therefore, the error correction system of Blu-ray Disc has the ability to handle long burst errors.

After analyzing the actual function of RSPC used in DVD system, we find the main function of horizontal checkout code is correct the random error and indicate the position of burst error, in other hand, the main function of vertical checkout code is correct the burst error according the marked position. Furthermore, we can see the ability of horizontal checkout code slightly remain, vertical checkout code, however, is more busy than horizontal. According this, in Blu-ray Disc system develop this error-correction method, which use the LDS (Long Distance Subcode) and BIS (Burst Indicator Subcode) in vertical replace the horizontal checkout code. BIS have powerful redundant checkout code which is deposited the important address information and control information, and the ability of error-correction is strong. The error position which corrected by BIS is called Picket, which can exactly direct the LDS which redundant ability is little weak correct the error in the data. So this error-correction method is called Picket code.

Picket code is an error correction system with a very efficient way of burst indication. The system is a "sandwich" model with pickets (columns) inserted in between columns of main data at regular intervals. Both the main data and pickets are protected by Reed-Solomon codes, but the extremely strong codes for pickets are independent of the former. When decoding, the picket columns are first corrected. The corresponding correction information is used to locate the possible burst errors in the main data. Then, the symbols at these locations can be flagged as erasure. [15]

A Blu-ray Disc error correction block (ECC block) can store 64 kilobytes of user data. LDS has 304 code words with 216 information symbols and 32 parity symbols giving a code word of length 248, and these code words are interleaved two by two in the vertical direction.

A Blu-ray Disc ECC block consists of 4 picket columns with equal space. Among them, the first picket at the left end is formed by the sync patterns. An unusual detection of the sync patter for this picket indicates the existence of a burst error similar to the knowledge that a symbol of a picket column had to be corrected.

Unlike the first picket, the other three pickets are protected by BIS codes, which have code words with 30 information symbols and 32 parity symbols giving a code word length of 62, and are interleaved into three columns of 496 bytes each. These BIS locations can be flagged as erasure when correcting the code words for the main data.

Next to the main data channel, the information symbols of the BIS-code form an extra data channel (containing addressing information), which allow for fast and robust detection of the addresses, and are independent of the main ECC. The addressing information is protected separately against errors with a Reed-Solomon code that has code words with 5 information symbols and 4 parity symbols.

Because both LDC code and the BIS code have equal number of parity symbols per code word, one Reed-Solomon decoder is sufficient enough to decode both. [15]

Compare with RSPC which adopted by DVD system, the correct ability of Picket code is improve greatly because it adopt the new error-correction method. First, the redundant check data are placed at the column direction. Second, the powerful redundant checkout code and the strong correct ability of BIS assure the address information and control information can be read accurately, at the same time, the error position will be showed. Third, LDS can correct the error easily according the error position which is already showed by BIS. The difference between PSPC and Picket code is showed in Table.1.

Table.1 Difference between PSPC and Picket code

	DVD(RSPC)	Blu-ray disc(Picket code)
The code rate of ECC	0.866	0.852
ECC block	32KB	64KB
sector	2064 bytes	2074.5 bytes
Construction of code	Product code	Long Distance Subcode Burst Indicator Subcode
The correct maximum fully correctable burst length	2912 ECC bytes	9920 ECC bytes(17.3mm)
The number of correct burst error(200ECC bytes)	5-14	32-49($349\mu m$)
The number of correct burst error(600ECC bytes)	3-4	10-16($1047\mu m$)

SIMULATION

From above, it is obviously that RS code is the basic thing for ECC code. Here, it will add two different error matrixes to simulate the process of the error-correction code for the DVD system.

In many articles [11, 12], the performance of RS code or RSPC code is evaluated in professional opinion, and it is required the researcher have abundant ECC knowledge. So it is difficult for those people who have interest in this area but only know a few about it. According this, a new method for evaluating the performance of ECC code is put forward, the method is based on the mathematical point, and it is not relate to physics.

In this method, original data are regard as a matrix which has 192 rows and 172 bytes. After RSPC coding, this matrix which is called RSPC Matrix will have 208 rows and 182 bytes as Fig.1 show. In Fig.1, it is obviously that RSPC had added 16 rows which called outer parity (PO) and 10 bytes which called inner parity (PI). Then, one error matrix which has random errors will add on RSPC Matrix, this error matrix is used for simulating the errors in optical disc storage. Finally, we will compare the matrix which after RSPC decoding with original matrix. If two matrixes are same, that is to say, RSPC can correct this random error. If not, that is because the amount of errors oversteps the RSPC correct capability.

In same steps, we will simulate the process of RS code.

We will calculate the retained errors number which after RSPC and RS only for one sector, because other sectors can also be simulated in same way. After calculating, the errors number divided by the amount of original data is the ratio which can show the capability of error-correction method, so we call this ratio as error-correction ratio.

In our experiment, the error-correction ratio is varying with error number. So we will draw the RSPC (and RS) error-correction ratio and error number. In order to show the error-correction ratio vary expressly, we define the error number as abscissa and the error-correction ratio power of hundred as ordinate. The result is show in Fig.2.

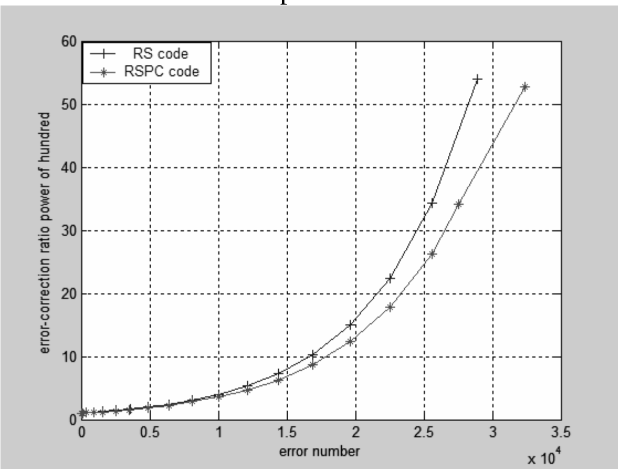

Fig.2 simulating result

Figure 2 shows the results obtained from studies of RSPC and RS code. It is clear from the figure that the error-correction capability of RSPC is much better than RS code. When error in optical disc is small (under 1.0×10^{-4}), the results are similar. At this moment, RS can correct the error data which hide in the original data. However, with error increasing, the result of RS coding is not satisfied. On the other hand, RSPC code is still good. But if the number of error is too large, the result is also including many errors. So more advanced method is taken in Blu-ray disc, which is picket code.

CONCLUSION

In this brief paper, only a part of the work in error-correction method has been surveyed. To sum up, we have revealed the three kinds of error-correction code for the optical disc, including CIRC for compact disc, RSPC for DVD system, picket code for Blu-ray disc. We had studied the coding and decoding process of those codes. Finally, we simulate the process of the error-correction code for the DVD system. We bring forward a new method for comparing RS and RSPC code in DVD system. This method compares RS and RSPC code in mathematical direction, which is not require any professional knowledge and more easily and intuitionistic for beginner. From the experiment, we can find the RSPC code is much better than RS code easily.

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