New robust coding scheme for wireless video transmission based on coefficient sampling

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ABSTRACT

Burst error is the most difficult problem to cope with in a wireless video transmission. In this paper, a new robust coding method is proposed, which is based on the spreading of burst error. We propose a coefficient sampling method for spreading, and show a projections onto convex sets (POCS) method fits well into this coefficient sampling method as a restoration method. The simulation results show that the proposed method restores the lost information very well.

Keywords: Burst error, coefficient sampling, coefficient group, interleaving, wireless channel, EREC, spread

1. INTRODUCTION

Among various problems of wireless channels, burst error is the most difficult one to cope with. It comes from the deep and short fading of electromagnetic wave, which is an inherent characteristic of a wireless media.

To solve the problem of burst error in video transmission, many researchers have proposed various methods. They have used unequal error protection (UEP)¹⁻⁷, robust codes or code insertion⁸⁻¹², multiple description coding (MDC)¹³ and automatic repeat request (ARQ).¹⁴

However, even when these methods are used, it is difficult to restore the heavily damaged data by burst error. This is because burst error damages information so severely that any method for it would suffer from the problem of setting a degree of protection.

Damaged information by burst error is usually concentrated around the position where burst error occurs. From the point of view of restoration, it is better to spread the damaged information over various locations, so that the reconstruction or concealment algorithm can benefit from the part of the information that is not corrupted. Figure 1 depicts two cases which show the effectiveness of spreading damaged information. Let the middle image block in case 1 be damaged by burst error and the information in the block be totally lost. The only way to recover the lost information is to use the neighboring block's data. Let's assume burst error spreads out to 3 blocks as shown in case 2. One third of the information of each block is damaged, but the decoder can use the remaining two thirds of the information as well as the neighboring block's data to recover the lost information. This is a better situation for restoration than case 1.

From this point of view, multiple description coding (MDC)¹³ is an attractive method, because it splits the entire block of information into several parts - which are called descriptions - with an induced correlation. The induced correlation is fully exploited to recover the lost information in the decoder. The effect of spreading of error is obtained by splitting information in this method. However, MDC assumes multiple physical paths which are not usually possible in wireless communication systems.

In this paper, we propose a new robust video coding scheme for a wireless environment, especially focused on restoration of texture information. In the proposed method, DCT coefficients of a block are divided into several coefficient groups (CGs). Each CG is encoded by the conventional encoding process - run-length coding and variable length coding (VLC) - and the generated bits are arranged in a predetermined position in the bit stream. The position is determined by an interleaved manner in order to prevent all of the block information from being damaged by burst error at the same time. We assume that there is one physical wireless link - not like the assumption of MDC¹³ - so that the bit stream is sent serially.

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Figure 1. Effect of spreading out burst error.

At the decoder, the received CGs are combined to make up the original coefficient block and the conventional decoding process is performed. If one CG is damaged by burst error, we utilize the remaining information - i.e., the remaining uncorrupted CGs - of the block to recover the damaged CG.

Our restoration algorithm uses the neighboring blocks and the uncorrupted CGs. It is based on the POCS method, where the uncorrupted part of information serves as another convex set.

This paper is organized as follows. Section 2 describes the proposed scheme in detail, and shows how coefficients are divided and how slots are ordered. In Section 3, restoration by POCS is explained. In Section 4, the simulation results are presented. Finally, Section 5 concludes the paper and mentions future work.

2. PROPOSED METHOD

The proposed method is shown in Figure 2. Before the run-length coding stage, a coefficient sampling is carried out. In this stage, zigzag-scanned 64 DCT coefficients are divided into several CGs. Each CG is independently run-length coded and Huffman coded. The CGs from each block are collected until the whole GOB is encoded. The collected CGs are put into slots in the slot ordering stage. The slot lengths are equalized by the EREC method.

Figure 2. Proposed encoder structure.

Each stage is explained in the following subsections.

2.1. Coefficient Sampling

Coefficient sampling stage is for splitting data into several groups. It can be performed both *before* and *after* the run-length coding and Huffman coding stage. However, the position of coefficient sampling stage must be before the run-length coding stage from the following reason :

One of the basic assumptions in EREC, which will be explained later, is that a block has an end code to identify the end of the block data. In H.263 standard, for example, the end code is signified by the last field in the run-length symbol,²⁰ but if we divide the block data into several pieces *after* the run-length coding and VLC stages, only one CG has an end code among all created CGs. Then, the divided data cannot be used in the EREC scheme.

Therefore, the proposed scheme divides the block data into CGs *before* the run-length and VLC encoding stages and encodes each CG. Figure 3 shows an example of dividing the transform coefficients of a block into 3 CGs.

Let the zigzag scanned coefficients in an 8×8 block b be $c_b(i)$; $i = 1, 2, \dots, 64$. As index i increases, $c_b(i)$ corresponds to the high frequency coefficient. These coefficients are divided as follows:

Let the number of CG be NCG (e.g., $NCG=3$ in the Figure 3). Let $CG_{(b,k)}(i)$ be the i th coefficient in k th CG in block b , where $k = 1, 2, \dots, NCG$, $i = 1, 2, \dots, N_k$. N_k is the number of coefficients in CG k , where

$$\sum_{k=1}^{NCG} N_k = 64,$$

and N_k 's must be as equal with one another as possible.

For example, if NCG is 3, $N_1 = 22$, $N_2 = 21$, $N_3 = 21$. $CG_{(b,k)}(i)$ is defined as

$$CG_{(b,k)}(i) \stackrel{\text{def}}{=} c_b((i-1) \times NCG + k), \quad i = 1, 2, \dots, N_k \quad k = 1, 2, \dots, NCG. \quad (1)$$

The divided coefficients are encoded by the conventional run-length coding and Huffman coding, which generates a bit stream of different lengths.

The transform coefficients are sampled in an interleaved way as in Eq. (1) because the created CGs must have equal importance. If, for example, the coefficients are divided sequentially as in Eq. (2), the resulting CGs have no equal importance.

$$CG_{(b,k)}(i) = c_b(NP_k + i), \quad i = 1, 2, \dots, N_s, \quad NP_k = \sum_{j=1}^{k-1} N_j, \quad NP_1 = 0. \quad (2)$$

In this case, the first CG is the most important because it has low frequency coefficients. However, the risk of being corrupted by burst error is the same for all the CGs. It is therefore unreasonable to divide CGs by an unequal importance as in Eq. (2).

2.2. Slot Interleaving

Bits from each CG are put into corresponding slots. If these slots are transmitted in the order of block, there is no advantage to dividing the data from one block. Consecutively damaged slots by burst error will turn out in the decoder as neighboring damaged blocks. Since restoration algorithms in the decoder must take advantage of using uncorrupted neighboring blocks, the slot order must be changed.

Therefore, as shown in Figure 4, we place each slot in an interleaved manner. Instead of being arranged in the order of the block, each slot is arranged so that slots of the same CG number are grouped together as shown in the Figure 4.

But if burst error occurs as shown in Figure 5, the neighboring blocks are still damaged. More interleaving is needed. To accomplish this, there must be another interleaving in the same slot number level. This is shown in Figure 6. The burst error no longer damages the neighboring blocks by this slot ordering.

2.3. Error-Resilient Entropy Code (EREC)

EREC was proposed by Redmill and Kingbury¹⁵ for preventing error propagation through block data which is encoded by variable length codes. We adopt this EREC method also for preventing error from propagating through CG boundaries. It is needed under the assumption that the data must be sent serially in real wireless channels, as mentioned in Section 1.

EREC is performed in our proposed scheme after slot ordering, which makes the lengths of the slots equal.

Figure 3. Coefficient sampling.

Figure 4. Slot interleaving.

3. RESTORATION

For comparison purpose, a simple zero substitution method will be mentioned. And then restoration by POCS will be explained.

3.1. Zero Substitution

The most simple restoration method is replacement of missing coefficients with zero coefficients. This simple method can be effective in high-frequency bands, where coefficients are mostly zeros. It is also effective for INTER blocks. This is because the DCT coefficients are inherently small (close to zero) by motion-compensation.

We can expect that the performance of zero substitution would be degraded for a complex image or a low quantization parameter (QP) value.

Figure 5. Corruption by burst error.

Figure 6. Slot interleaving in sublevel.

3.2. POCS (Projection Onto Convex Sets)

POCS is an effective spatial error concealment method. Its main idea is that if a point is iteratively projected onto formulated convex sets one by one, it will eventually converge to the intersection point of those convex sets.

Therefore, to apply the POCS algorithm, we must formulate the convex sets. In this subsection, we restore damaged blocks by a POCS algorithm, where an additional convex set is defined.

Huifang and Wilson¹⁶ proposed a method of concealment by POCS. They used two convex sets as shown in Figure 7. A damaged block with 8 uncorrupted neighboring blocks are formulated into a 24×24 large block. The first convex set is composed of the known values of the neighboring blocks. The second convex set comes from a smoothness constraint. The 24×24 block is expected to be smooth enough that its transformed block has no large high-frequency coefficients. Therefore, the coefficients outside the arc must be zero.

However, we can have one more convex set if we use the proposed coefficient sampling method. Because we don't lose all DCT coefficients, the coefficients without error can be naturally formulated into a convex set. Therefore, we propose to make one more convex set. Figure 8 shows the third constraint. It is assumed that one of two CGs is damaged in this figure. The white points indicate the lost coefficients, and the black points the correctly received coefficients. The third constraint is that the correctly received coefficients must be used in the damaged 8×8 block. We can say this is another adoption of a method proposed by Sezan and Tekalp,¹⁷ where the part of DCT coefficients are formed as a convex for suppressing artifacts.

The overall algorithm is shown in Figure 9. The dotted line specifies the conventional method of Huifang. The specific procedure is as follows :

Figure 7. First and second constraint.

Figure 8. Third constraint.

1. The known coefficients are set, and the lost coefficients are replaced by zero. Perform IDCT of the block. Then, the resulting luminance block serves as an initial value of the damaged block.
2. The neighbor blocks are filled with the known value. (*first constraint*)
3. Perform $N \times N$ DCT. (N is a large block size.)
4. Prune the high-frequency coefficients. (*second constraint*)
5. Perform $N \times N$ IDCT.
6. Obtain the center 8×8 block.
7. Perform 8×8 DCT.
8. Set the known coefficients without changing the others. (The white points in Fig. 8) (*third constraint*)
9. Perform 8×8 IDCT.
10. See if the resulting 8×8 block is the same as the one in the previous stage. If not, go to step 2 and repeat the process. If yes, stop it.

Figure 9. Overall POCS algorithm.

Figure 10. Before POCS - NCG=1.

Figure 11. After POCS - NCG=1.

4. SIMULATION RESULTS

The proposed algorithm is tested using H.263 standard. Simulation is done with the error pattern file from ITU-T SG16.¹⁸ We assume that the header and motion vector information are protected strongly enough not to be damaged by burst error.

Figure 10 and 11 show examples of results where no coefficient sampling is done, i.e., the number of CG (NCG) is 1. Figure 10 shows the result before the POCS algorithm, and Figure 11 after the algorithm. The POCS algorithm doesn't show a perfect reconstruction of the damaged blocks.

Figure 12 and 13 show the cases of 4 CGs. Because part of information of a block is preserved in the decoder, the reconstruction is better than the case of 1 CG.

However, the restoration method cannot exactly reveal its effect if we simulate it with the error pattern file. This is because the damaged part of an image takes too small a part of the image. In other words, there are too few samples to evaluate the performance of the restoration method. Also, the position of the damaged block is not fixed as the NCG changes, as already seen in Figure 10 and Figure 12. We cannot tell if it is good or bad if we have different damaged blocks, because the restoration performance is dependent on the image content. To show the performance of the restoration algorithm more clearly, a simulation environment is devised as follows.

We assume most of image blocks are damaged for obtaining many samples. The neighboring blocks of the damaged block are assumed to be uncorrupted, because the probability of the event that they are damaged at the same time is very low by the proposed interleaving method. The determined position of the damaged blocks is shown

Figure 12. Before POCS - NCG=4.

Figure 13. After POCS - NCG=4.

in Figure 14 by black blocks. For a fair comparison, it is necessary to make the number of the damaged blocks increase proportionally to the increase of the NCG. In the case of 5 CGs, every block is assumed to be damaged.

This simulation is performed for various images - frames in Akiyo, Coast Guard, Stefan sequences - under the assumption that each CG is damaged with the same probability.

Table 1 shows the enhancement of the picture quality of the damaged block by the POCS algorithm. Note that this PSNR is calculated only on the damaged blocks. As NCG increases, the restoration performance gets better. It shows that the restoration algorithm benefits from the remaining part of information.

Table 1. POCS result only for the damaged block - Akiyo (PSNR in dB).

Number of CG	Zero Substitution	POCS
1	14.61	33.31
2	22.21	35.74
3	26.98	36.67
4	30.48	37.78
5	32.75	38.54

However, this is still not a fair comparison because the number of the damaged blocks increases as NCG increases. That is, we must note that we preserve part of information for a damaged block in return for increase of the number

Figure 14. Test block positions.

of damaged blocks, as already shown in Figure 1. Therefore, all blocks in the image should be taken into account in calculating the PSNR, whether it is damaged or not.

Table 2 shows the result which takes into account all the image blocks when calculating PSNR. ZS in the table refers to zero substitution method.

Table 2. POCS result(all in dB).

Image	Akiyo		Coast Guard		Stefan	
NCG	ZS	POCS	ZS	POCS	ZS	POCS
1	14.69	31.02	12.96	29.34	12.26	25.44
2	21.98	31.61	19.51	29.79	17.72	26.11
3	24.34	31.28	22.27	30.08	19.61	25.97
4	26.43	31.97	23.27	29.95	20.65	26.19
5	27.83	32.24	24.46	30.10	21.53	26.17

The zero substitution method still enhances the restored picture quality as NCG increases. The POCS method shows better performance over the zero substitution method, but little improvement along NCG increase. This is because when calculating the PSNR, blocks which are not assumed to be damaged mitigate the effect of the restoration performance of corrupted blocks. The POCS algorithm is not enough to elevate the restored picture quality over this mitigation effect. There must be a more effective restoration method other than POCS, and this will be the focus of future work.

However, note that the subjective quality improves as NCG increases, as shown in Figure 15. The damaged blocks are more annoying when burst error does not spread into other blocks.

5. CONCLUSION

In this paper, we proposed an error resiliency method against burst error in a wireless channel. The proposed method consists of splitting the transform coefficients into several groups, encoding each group and sending it in an interleaved manner so that the information from one block will not be lost at the same time. This gives the restoration algorithm the advantage that it can utilize the remaining information for restoring the damaged information.

We showed the simulation results of the POCS restoration method. The results showed that as NCG increases, the picture quality of the damaged block increases. Also, the subjective quality was shown to increase as NCG increased.

(a) NCG=1

(b) NCG=4

Figure 15. Subjective quality enhancement(Akiyo).

Note that the POCS algorithm is just an example of the restoration algorithm. There can be many other algorithms that use the uncorrupted CG for boosting their restoration performance. It remains as our future work.

REFERENCES

1. Chun-Hsien Chou and Chi-Wei Chen, "A Perceptually Optimized 3-D Subband Codec for Video Communication over Wireless Channels," *IEEE Trans. on CSVT*, Vol. 6, No. 2, pp. 143-156, April 1996.
2. Han-Seung Jung, Rin-Chul Kim, Sang-Uk Lee, "On the Robust Transmission Technique for H.263 Video data Stream Over Wireless Networks," *Proceedings of ICIP 98*, Vol.3, pp. 463-466.
3. Yasushi Koyama and Susumu Yoshida, "Error Control for Still Image Transmission over a Fading Channel," *IEEE 45th Vehicular Technology Conference*, Vol. 2, pp. 609-613.
4. Chih-Chin Liu, Shu-Chin Su Chen, "Providing Unequal Reliability for Transmitting Layered Video Streams over Wireless Networks by Multi-ARQ Schemes," *Proceedings of ICIP 99*, Vol. 3, pp. 100-104.
5. R. Chandramouli, N. Ranganathan, Shivaraman J. Ramadoss, "Empirical Channel Matched Quantizer Design and UEP for Robust Image Transmission," *Data Compression Conference 98*, pp. 531.
6. Yasuhiro Imai, "Development of Digital Mobile Radio Facsimile," *International Carnahan Conference on Security Technology*, 1989, pp. 261-266.
7. Celso de Almeida and Reginaldo Palazzo Jr., "Two-Dimensional Interleaving Using the Set Partitioning Technique," *IEEE International Symposium on Information Technology 1994*, pp. 505.
8. Yi-Huang Han and Jin-Jang Leou, "Detection and Correction of Transmission Errors in JPEG Images," *IEEE Trans. on CSVT*, Vol. 8, No. 2, pp. 25-30, April 1998.
9. Sheila S. Hemami, Tader Chang, Richard Lau, "Resynchronizing Variable-Length codes for Robust Image Transmission," *Data Compression Conference 99*, pp. 529.
10. Ken'ichiro Ogura, Akio Miyazaki, Yoshihiko Akaiwa, "An Error Resilient Still Image Transmission System for Mobile Radio Communication," *IEEE 49th Vehicular Technology Conference*, Vol. 3, pp. 2004-2008.
11. Raj Talluri, Karen Oehler, Thomas Bannon, Jonathan D. Courney, Arnab Das, and Judy Liao, "A Robust, Scalable, Object-based Video Compression Technique for Very Low Bit-Rate Coding," *IEEE Trans. on CSVT*, Vol. 7, No. 1, pp. 221-233, February, 1997.
12. Vasanth R. Gaddam, Sathyanarayan S. Rao, "Error Correcting Codes for Robust Transmission of Scalable Video Bitstream over Fading Channels," *Thirty-Second Asilomar Conference on Signals, Systems & Computers 98*, Vol. 1, pp. 42-46.
13. Doo-Man Chung and Yao Wang, "Multiple Description Image Coding Using Signal Decomposition and Reconstruction Based on Lapped Orthogonal Transforms," *IEEE Trans. on CSVT*, Vol. 9, No. 6, pp. 895-908, September 1999.

14. M. Khansari, A. Jalali, E. Dubois and P. Mermelstein, "Robust Low Bit-Rate Video Transmission over Wireless Access Systems," ICC 94, Vol. 1, pp. 571-575.
15. David W. Redmill and Nick G. Kingsbury, "The EREC : An Error-Resilient Technique for Coding Variable-Length Blocks of Data," IEEE Trans. on Image Processing, Vol. 5, NO. 4, pp. 565-574, April 1996.
16. Huifang Sun, and Wilson Kwok, "Concealment of Damaged Block Transform Coded Images Using Projections onto Convex Sets," IEEE Trans. on Image Processing, Vol. 4, No. 4, pp. 470-477, April 1995.
17. M. Ibrahim Sezan and A. Murat Tekalp, "Adaptive Image Restoration with Artifact Suppression Using the Theory of Convex Projections," IEEE Trans. on ASSP, Vo. 38, No. 1, pp. 181-185, Jan. 1990.
18. ITU-T STUDY GROUP 16, *WCDMA error Patterns at 64 kb/s*, Q11-F-05.
19. Yao Wang, and Qin-Fan Zhu, "Error Control and Concealment for Video Communication : A Review", Proceeding of IEEE. Vol. 86, No. 5, May 1998.
20. ITU-T Recommendation H.263, *Video Coding for Low Bitrate Communication*.