Multiple Description Coding using Unequal MDSQ in Wavelet Domain

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Abstract: Error resilience for image coding is an important component of multimedia communication system. Error resilience schemes address loss recovery from the compression perspective. Multiple description coding (MDC) is one of the error resilience techniques promising for robust video transmission. It is the way to achieve tradeoff between the compression efficiency and the reconstruction quality from one description. In multiple description coding, there are several ways in the methods to separate description such as scalar quantization, correlating transform and quantized frame expansion.

In this paper, we consider Multiple Description Scalar Quantization (MDSQ) to wavelet domain. Conventional MDSQ schemes considered description with equal weights in each sub-bands. But, we can see that the each sub-bands is unequal contribution to whole image quality. Therefore, we experiment the multiple description scalar quantization with unequal weight in each sub-bands. We design MDSQ table to make probability of zero index high, which gives high efficiency in arithmetic symbol coder. We also compare our proposed method with the conventional methods and show improved performance in terms of redundancy-rate-distortion.

1. Introduction

In general, a channel may not offer any quality of service (QoS) guarantees to image transmission. Therefore, there are many challenging issues that need to be addressed to designing protocols and mechanisms for image transmission. Many solutions on the issues take approach to present solutions from both transport and compression perspectives. By transport perspective, we do not use the specific image properties because the transmitting data is generic. By compression perspective, we achieve the image properties on compression domain. The multiple description coding is the one challenging to guarantee the data resilience for channel [1][2].

Multiple Description Coding (MDC) is a source coding technique in which the source is encoded into multiple descriptions, which are transmitted over different channels to the receiver. When all the descriptions are available at the receiver a high quality reconstruction of the source is possible. However, in the absence of some of the descriptions at the receiver the quality of reconstruction should still be acceptable.

MDC is another way to achieve tradeoff between compression efficiency and robustness to packet loss. With MDC, a raw image is compressed into multiple streams. Each of descriptions provides acceptable visual quality. However, the advantages of MDC do not come for free. To make each description provide acceptable visual quality, each description must carry sufficient information about the original image. This will reduce the compression efficiency compared to conventional single description coding. In addition, although more combined descriptions provide a better visual quality, a certain degree of correlation between the multiple descriptions has to be embedded in each description, resulting in further reduction of the compression efficiency. Current research effort is to find a good tradeoff between the compression and reconstruction quality from one description [3].

In the context of MD coding, it must be possible to decode each description independently whether other descriptions are available at the decoder or not. As a result, if the coding technique employed makes used of explicit side information, enough side bits must be spent within each description to ensure that each one of them can be decoded independently of the others. However, side information is inherently different from basic data in that, in general, it does not admit approximate representations. In this paper, we consider the special case of MDC with two descriptions using the unequal MDSQ in wavelet based image coding.

MDC are based on the natural correlation in the signal that remains even after compression, and allows interpolation of missing segments. Early researches in MDC are beginning at the information theory to make independent channel splitting in speech compression. Jayant proposed a separation of odd and even samples in a speech coding method for channel splitting [4]. Jayant's simple system had been motivated by random losses in packet-switched telephony. Rate-distortion theoretic results on MDC of memory-less sources are presented in [5]. Many years later, Vaishampayan reinvent the technique for memory-less sources and analyzed in detail and implemented MDC using scalar quantizers multiple scalar quantization (MDSQ) [6]. Other methods to MDC are correlation transform [7] and quantized expansion coefficients (QFE) [8]. The pairwise correlating transform is introduced dependencies between descriptions transmitted over different channels. So, quantized expansion of coefficients are great similarity to a block channel code and attempts to alleviate the "cliff effect".

We present an algorithm to have good performance MDSQ in Wavelet domain. The algorithm uses error resilient coding to transmit image data.

In Section 2, we present a brief overview of the MDSQ basic algorithm and formulation to consider the implementation problem. Section 3 describes the technique to separate description in wavelet domain and wavelet transform quantization scheme. We mention basic functions used in our proposed algorithm. In Section 4, we explain the design scheme of the proposed unequal MDSQ image coding. In Section 5, we present experimental result of proposed algorithm and compare the performance between our scheme and another MDSQ scheme in wavelet domain. Furthermore, we discuss a several properties in our proposed scheme. Finally, we present the conclusion and discuss areas requiring further work in Section 6.

2. Multiple description scalar quantizer

How to separate a description into many descriptions is very important issue in MDC. There are many separating algorithms such as MDSQ, correlating transform and quantized expansion of coefficients. Following the wavelet decomposition, we use the MDSQ to produce two correlated descriptions based on wavelet transform.

The MDSQ used in this paper is to separate the description by considering the quantization level of each coefficient symbols. Figure 1 illustrates a MDSQ scheme. In the case of the MDSQ, two indices i and j are generated as follows. The sample X is mapped to a cell of square matrix with m rows and m columns. This is done by the index assignment. The index assignment square matrix is shown at Figure 1. Then i and j are the row and column indices of the cell respectively. The redundancy is controlled by number of diagonals at index assignment. The correlation between the two indices i and j is inversely proportional to the number of diagonal used [6].

	~	A	B	C	D	E	~
~	~	~					
a	~	●	●				
b		●	●	●			
c			●	●	●		
d				●	●	●	
e					●	●	~
~						~	~

● : coefficient
Large alphabet : transmite symbol for description 1
Small alphabet : transimte symbol for description 2

Figure 1. Index assignment square matrix in MDSQ

Figure 2 shows general MDSQ system block diagram. The input data X is quantized in symbol $\tilde{X}$ by wavelet quantizer. The $\tilde{X}$ is mapped to a pair of indices i and j by index assignment. The i and j are separately encoded and transmitted over the two independent channels. Each of the indices has correlation to be determined at index assignment step. In MDSQ, the reconstructed image quality to received single description is dependent on how to design the index assignment.

When both indices are received, a central decoder maps them to a reconstruction value $\hat{X}_0$. If only one index is received, side decoders are used which map i to $\hat{X}_1$ and j to $\hat{X}_2$ respectively. The average distortion of central decoder is:

$$D_0 = E[(X - \hat{X}_0)^2] \ . \qquad (1)$$

The average distortion of side decoder is:

$$d_1 = E[(X - \hat{X}_1)^2], \ d_2 = E[(X - \hat{X}_2)^2] . \qquad (2)$$

In this process, the quantizer, index assignment, central decoder and side decoders are constituents in the MDSQ. The goal of MDSQ is to minimize the distortion in optimally bit-rate allocated transmit channel.

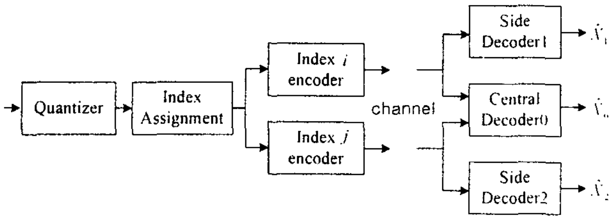


Figure 2. Multiple description coder

3. Multiple description in wavelet domain

The JPEG standard has been in use for almost a decade now. It has proved a valuable tool during all these years, but it cannot fulfill the advanced requirements of today. And so, a new call for contributions was launched for the development of a new standard for the compression of still image, the JPEG2000 standard. The JPEG members selected a discrete cosine transform and Huffman coding based method in 1988. But, the JPEG2000 standard selects a wavelet transform and arithmetic coding scheme based compression system. The wavelet have been used as a linear decorrelating transform in order to attain some of the best known results in terms of coding efficiency.

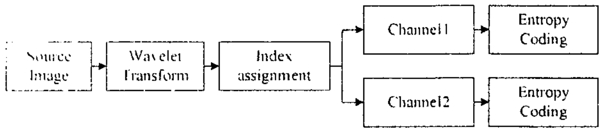
In general, MDC in wavelet domain uses MDSQ having equal diagonal depth in each wavelet sub-bands [9]. Figure 3 shows basic architecture of a diversity system using a MDSQ in wavelet domain. At the first, take a wavelet transform of the input image, and apply the input quantizer to each coefficient. The quantization is the process by which the coefficients are reduced in precision. Each of the transform coefficients $a_b(u,v)$ of the sub-band b is quantized to the value $q_b(u,v)$ according to the formula:

$$q_b(u,v) = sign(a_b(u,v)) \left\lfloor \frac{|a_b(u,v)|}{\Delta_b} \right\rfloor . \qquad (3)$$

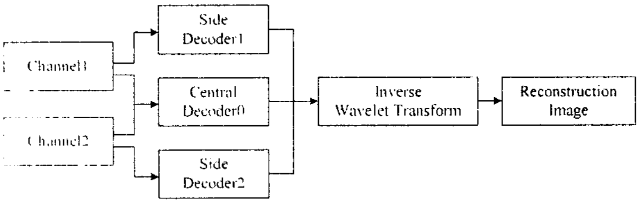
The quantization step-size Δ_b is represented relative to the dynamic range of sub-band b. In other word, the quantization supports different quantization step-size for each sub-band. However, one quantization step-size is allowed per sub-band. The dynamic range depends on the number of bits used to represent the original image. In the implementation, dynamic range for each sub-band is represented as $Max_b \sim Min_b, (b = 1,2,3)$.

Next step, we separate the index for each coefficient by MDSQ method explained in section 2. Each quantized wavelet coefficients is mapped to two indices of description 1 and 2. So, the dynamic range of each indice is represented as $Max_b / k \sim Min_b / k, (k = 1,2,...)$. The k is number of diagonals in MDSQ square matrix. In fact, thus the indices of each description are transmitted through the channel. Number of transmitted word determines the amount of bit-stream in real channel. So, the dynamic range of each index is related to size of transmitted bit-stream.

Separated indices are coded statistically. Entropy coding is performed by means of an arithmetic coding system, which compresses binary symbols according to an adaptive probability model.



(a) Encoder



(b) Decoder

Figure 3. Proposed MDSQ architecture in Wavelet domain

4. Proposed algorithm

In the high frequency sub-band stage, the probability of zero coefficients is large in natural image. When both descriptions received, the indices are mapped to the original coefficient. But only one description is received, the indices of lost description are mapped to the average coefficient value in MDSQ. If diagonals in MDSQ square matrix are two, the maximum distortion of each coefficient is 0.5 in integer implementation. If the number of diagonal is increased, the maximum distortion of each coefficient becomes large. So, we design the MDSQ square matrix mapping to zero coefficient having large probability in side decoder. Figure 4 shows indexing scheme of our method. In sub-band 3, the remapped coefficients are important in whole image quality. Because of the coefficient's large variance and random distribution, we use the MDSQ index table having equal diagonals in all coefficient range. In the sub-band 2 and 3, the probability of zero coefficient presented is large. Thus, we use unequal index table that has the different number of diagonals in same dynamic range. When all descriptions received, amount of bit-stream is decreased because probability of the zero indices is increased in the next entropy coder. When one description lost, in the sub-band 2 and 3, most of remapped coefficients go to zero. If we use equal diagonal index table, the remapped coefficient value take average value of the coefficients in single index. It increases the total distortion. So, we expect the good reconstructed image quality with unequal diagonal index table.

(a) subbands in wavelet domain

	~	-2	-1	0	1	2	~
~	~	~					
-2	~	●	●				
-1		●	●	●			
0			●	●	●		
1				●	●	●	
2					●	●	~
~						~	~

(b) MDC indexing in subband 3

	~	-2	-1	0	1	2	~
~	~						
-2		●					
-1			●	●			
0			●	●	●		
1				●	●		
2						●	
~							~

(c) MDC indexing in subband 2

	~	-2	-1	0	1	2	~
~	~						
-2		●					
-1			●	●			
0			●	●	●		
1				●	●		
2						●	~
~						~	~

(d) MDC indexing in subband 1

Figure 4. Index assignment of our method

If the probability of a zero index increases, amount of bit-stream is decreased through the arithmetic coder, and reduce the total distortion in side decoder at the same time.

5. Experimental results

We use the standard 512*512 Lena image in experimental environment. We use JPEG2000 standard wavelet decomposition filter, Quantization step-size, and arithmetic coder.

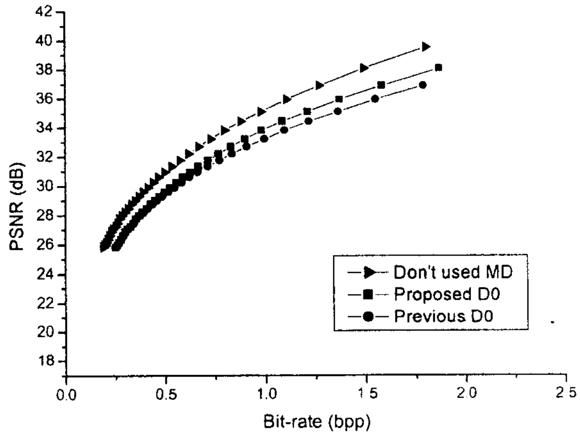


Figure 5. Rate-distortion curves of central encoder

In general method, equal index table has two diagonals in all sub-bands. In proposed method, we use unequal index table in sub-band 2 and 3. Total dynamic range of index assignment table in the all sub-band is same. Figure 5 illustrates the rate-distortion curve in both descriptions received. At 1 bpp, we have improvement about 1 dB. Rate-distortion curve shows better improvement in high bit-rate.

Rate-distortion curve of single description received is shown in Figure 6. The distortion of side decoder is greatly improved about 5 dB in whole bit-rate range. The reason of this is to reduce the distortion due to increasing probability zero coefficients in side decoder.

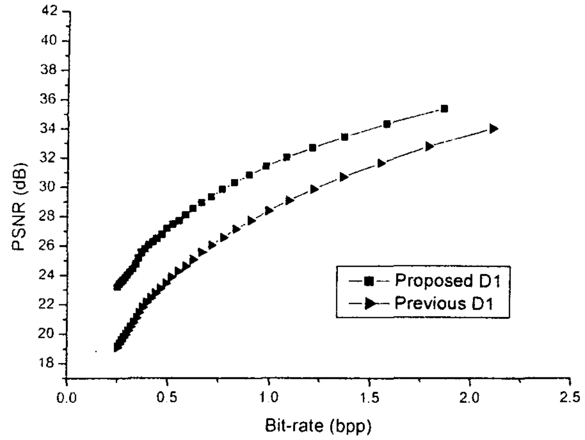


Figure 6. Rate-distortion curves of side decoder

Figure 7 shows reconstructed images in both descriptions received and one description received. Figure 7(a) is the image of single description received with 31.74 dB at 1 bpp. Figure 7(b) is the image of all descriptions received with 34.43 dB at same bpp. If test image has more high components of frequency, the improvement in visual quality is not guaranteed. However, this problem is not only this environment.


(a) (b)

Figure 7. Reconstructed image: (a) in single description received (31.74dB, 1bpp) (b) in all descriptions received (34.43dB, 1bpp)

6. Conclusions

The paper described an efficient MDC scheme for image coding. We presented implementation and consideration of error resilient data transmission. Currently, the wavelet transform and arithmetic coder are used in many applications. Our presented algorithm is based on this system. Our proposed method uses the property that has unequal importance of each wavelet sub-bands to image quality as a whole. We design the index table consider to have high probability of wavelet coefficient, and having many zero index in MDSQ. The index symbol probability is considered in arithmetic coder. It is the cause of good performance in MDC scheme. Therefore, we achieved the better improvement in experiments. In above section, we get implement about 4 dB in whole bit-rate range, which is only one description is received. The experiments demonstrate the ability of this coding scheme to convey a reasonable amount of information to the receiver even when one channels is completely lost.

The MDC is very useful at application require various quality levels. In multi-path channel environment, the MDC is very useful. Further more, in the error-prone like wireless channel environment, error resilient coding scheme (like MDC) is required. We will study more applicable algorithm in error-prone channel.

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