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NOVEL TWO-CHANNEL MULTIPLE DESCRIPTION CODING FRAME BASED ON THE SFQ ALGORITHM

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Abstract. *A two-channel MDC framework based on the Space-Frequency Quantization (SFQ) algorithm is proposed in this paper. Redundancy used in this frame is introduced by the overlap of the optimization sets. For each channel contains the information from all the three directions, the reconstruction of the one single channel can give a good estimation of the original information. Good experimental results show the efficiency of this new proposed method.*

Keywords: Wireless communication, Multiple description coding, Space-frequency quantization, Optimization sets

1. **Introduction.** With the rapid development of wireless communication, more and more transmission robustness problems have emerged. Though there are many other traditional techniques to solve these problems such as the Forward Error Correction (FEC) technique [1], the Auto Repeat Rrequest (ARQ) technique [2] and the Hybrid Error Correction (HEC) technique [3], the high design complexity and the high secondary congestion risk are their shortcomings.

The Multiple Description Coding (MDC) technique which was firstly introduced in the Shannon Conference in 1979 has been widely used in the network [4] for its simple design process and its good performance in practical applications. The main idea of MDC is to introduce some redundancy among the different descriptions. If one of descriptions is lost, we can use the received information to estimate the original and give an acceptable result. And if all descriptions are perfectly received, we can obtain a better reconstruction but with lower efficiency for the more than enough information.

The two-channel MDC framework is shown in Figure 1.

Here $\{X_K\}$ is the original information. $\left\{\hat{X}_K^{(1)}\right\}$ and $\left\{\hat{X}_K^{(2)}\right\}$ are two side reconstructions. And $\left\{\hat{X}_K^{(0)}\right\}$ is the central reconstruction. To evaluate the result, we usually use D_s^1, D_s^2 and D_c^0 to represent the two side distortions and the central distortion respectively.

$$D_s^i = \sum_K \left(\hat{X}_K^i - X_K\right)^2, \quad i = 1, 2 \tag{1}$$

$$D_c^0 = \sum_K \left(\hat{X}_K^{(0)} - X_K\right)^2 \tag{2}$$

Generally speaking, the MDC techniques can be simply classified into the quantization based and the transform based MDC techniques for the different redundancy introducing ways. Among these algorithms, the Multiple Description Scalar Quantization (MDSQ)

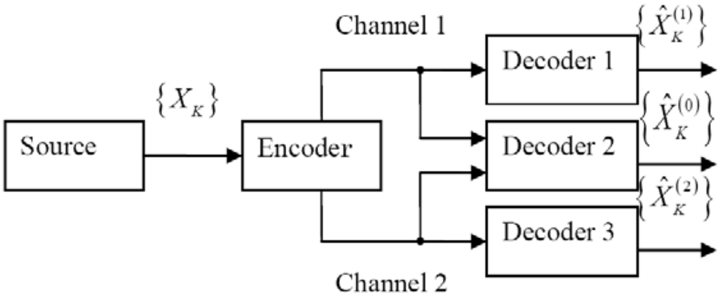


FIGURE 1. Two-channel MDC frame

	000	001	010	011	100	101
000	0	1				
001	2	3	5			
010		4	6	7		
011			8	9	11	
100				10	12	13
101					14	15

FIGURE 2. Index assignment for SQMDC

coding methods [5,6] and the Multiple Description Vector Quantization (MDVQ) coding methods [7,8] belong to the quantization-based methods. An example for commonly used scalar quantization based MDC frame can be shown in Figure 2.

As we can see from Figure 2, if the two coordinates are used for the two descriptions, the location design will have a great impact on the algorithm performance. In fact, more efficient algorithms need more complex quantizer design processes. So, more and more research has been implemented on the transform-based MDC frameworks to search for more easy and useful algorithms, for example, the correlation transforms based MDC frames [9]. It makes full use of the transform matrix to introduce some redundancy among the separate information. Key point for the transform-based MDC framework is to design a proper transformation matrix. Following matrix T is a classical example for the transform based methods. Two uncorrelated information $\bar{A}$ and $\bar{B}$ can be transformed into two related ones $\bar{C}$ and $\bar{D}$ by applying the matrix T onto the original information. And we can control the strong or weak correlation of the transform T by modifying the parameter θ.

$$\mathrm{T} = \begin{bmatrix} \sqrt{\frac{\cot\theta}{2}} & \sqrt{\frac{\tan\theta}{2}} \\ -\sqrt{\frac{\cot\theta}{2}} & \sqrt{\frac{\tan\theta}{2}} \end{bmatrix}, \quad \mathrm{T}^{-1} = \begin{bmatrix} \sqrt{\frac{\tan\theta}{2}} & -\sqrt{\frac{\tan\theta}{2}} \\ \sqrt{\frac{\cot\theta}{2}} & \sqrt{\frac{\cot\theta}{2}} \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} \bar{\mathrm{C}} \\ \bar{\mathrm{D}} \end{bmatrix} = \mathrm{T} \begin{bmatrix} \bar{\mathrm{A}} \\ \bar{\mathrm{B}} \end{bmatrix}, \quad \begin{bmatrix} \bar{\mathrm{A}} \\ \bar{\mathrm{B}} \end{bmatrix} = \mathrm{T}^{-1} \begin{bmatrix} \bar{\mathrm{C}} \\ \bar{\mathrm{D}} \end{bmatrix} \tag{4}$$

Another simple example can give a more clear impression for this kind of algorithm as shown in the following. Suppose X is a two-dimensional vector, x_1 and x_2 are two coordinates. The matrix F is singular matrix and there must be some correlation among the three coordinates of vector Y. This kind of redundancy introducing way can be called the frame expansions method and it also can be seen as one of the transform based methods.

$$\underbrace{\begin{bmatrix} y_1 \\ y_2 \\ y_3 \end{bmatrix}}_{Y} = \underbrace{\begin{bmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{bmatrix}}_{F} \underbrace{\begin{bmatrix} x_1 \\ x_2 \end{bmatrix}}_{X} \tag{5}$$

Being called the mathematics microscope wavelet has been proved to be useful in many signal processing areas [10,11]. One of the most famous research areas is the multimedia compression technique [12,13]. The reason for wavelet to realize this process comes from its special multiresolution analysis structure property. Based on the different coding effect, wavelet compression coding algorithms can be probably classified into the embedded coding algorithms and the non-embedded coding algorithms. The EZW algorithm and SPIHT algorithm [14,15] belong to the embedded algorithms. And the spatial orientation tree used in the SPIHT algorithm can be seen as the improvement of the zerotree used in the EZW algorithm. The spatial orientation tree can be shown in Figure 3.

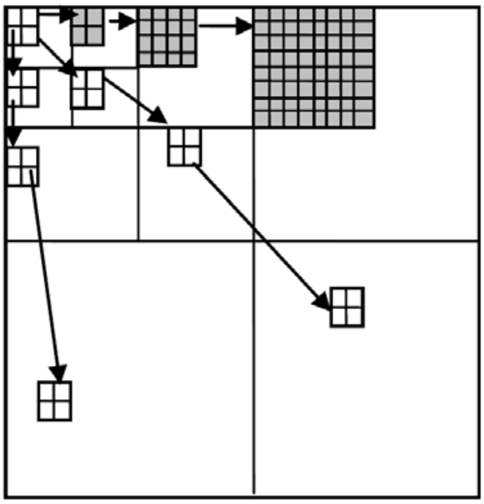
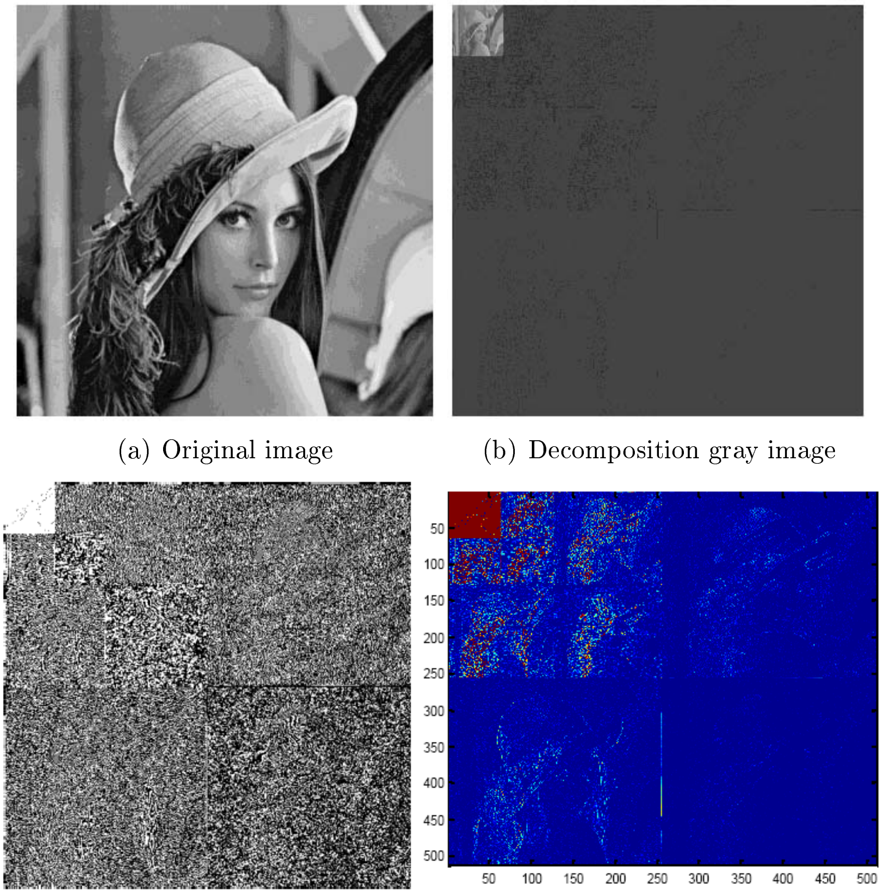


FIGURE 3. Space orientation tree structure

As other transmission processes, the first step for MDC is compression. In fact, there have been many papers proposed which were based on such embedding coding algorithms. The SFQ algorithm is one of the most efficient coding algorithms that belong to the non-embedded algorithms [16]. Both of the two kinds of wavelet based coding algorithms are based on the famous tree-structure decomposition image after applying the DWT. As we can see from Figure 4, every 'wavelet tree' may contain the most part information of one local area of the original image. In order to give a clear description of the special structure of the multiresolution results, we give three structure images to check it.

Actually, many transform-based MDC frameworks based on wavelet have been proposed these years [17,18]. For example, an MDSQ-based wavelet algorithm which is presented in reference [19] belongs to this kind of MDC framework. Many algorithms based on the embedded wavelet coding algorithms have been introduced in MDC research these years. The Embedded Zero Wavelet (EZW) algorithm based MDC frameworks and the Set Partition in Hierarchical Tree (SPIHT) algorithm based MDC frameworks are the examples [20]. Little attention has been paid for the non-embedded coding algorithms based MDC frameworks for its high computational complexity. On the other side, high encoding efficiency and the spatial orientation tree based coding algorithm can bring more efficient methods for information division in MDC frameworks.



(a) Original image (b) Decomposition gray image

(c) Decomposition binary image (d) Rectilinear path decomposition image

FIGURE 4. Wavelet decomposition results

2. Prior Work.

2.1. Two-channel MDC framework. We use the two balance channel in this paper, which means that the two bit rates of the two coders are approximately the same. The performance is evaluated by PSNR value at the same bit rates. The definition of PSNR for 256 gray-scale images is shown as follows:

$$PSNR = 10 \times \log\left(\frac{255^2}{MSE}\right) \tag{6}$$

Here MSE represents the mean square error value defined as follows.

$$MSE = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left(O\left(i, j\right) - R\left(i, j\right)\right)^2 \tag{7}$$

where M and N are the number of the rows and columns in original image, respectively. O and R represent the original and reconstructed images, respectively.

2.2. SFQ algorithm. The SFQ algorithm was firstly introduced in reference [17]. Figure 5 gives its basic coding process.

This algorithm is an optimization problem and the optimization equation can be shown as Formula (8).

$$\min_{\{q \in Q, S \subset T\}} \left\{J\left(q, S\right) = D\left(q, S\right) + \lambda R\left(q, S\right)\right\} \tag{8}$$

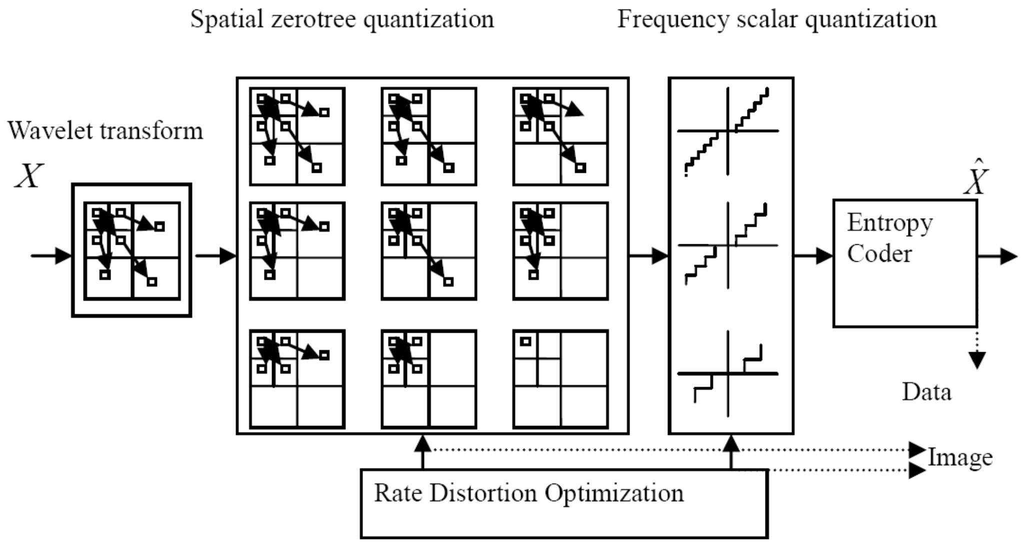


FIGURE 5. SFQ coder

Here, q and Q represent a certain quantization step and the set of quantization steps, respectively. S and T represent a certain type of zerotree-quantization tree and the set of all possible types of zerotree-quantization trees. $D(q,S)$ is used here to minimize the distortion under the optimal zerotree quantization and the scalar step choice at a certain fixed bit rate. $R(q,S)$ is the constraint condition and λ is the mass factor to balance bit rate against distortion. We use a fast iterative algorithm to solve this Lagrange multiplier problem in this paper. The basic idea of such a fast method is shown in Formula (9).

$$\max_{\lambda \geq 0}, \min_{q \in Q}, \min_{S \subset T} \{D(q,S) + \lambda [R_{data}(q,S) - R_b]\} \tag{9}$$

Firstly, under the fixed q and λ values, the optimal spatial subtree S is found. Then, the quantization step size q will be found. Finally, the λ value can be determined. Here, R_b is the estimation of the bit rate. Good performance of this algorithm has been compared with other classical tree structure based algorithms. The experimental results show the high compression efficiency. However, the high complexity restricts its development in the application. Therefore, little attention has been paid to it and little work has been done for its practical application. In fact, zerotree structure coding method has some advantage for the information splitting of MDC. We introduce a step by step optimization algorithm into this SFQ algorithm based MDC framework here.

3. **Proposed Method.** As we can see from Figure 5, the SFQ algorithm has two optimization sets. A new optimization set division method is introduced here to implement the coding process and to form the two MDC descriptions. Our proposed method can be described as follows.

1) Suppose T is the spatial zerotree quantization set which contains all the nine types of zerotree from three directions.
2) Firstly, we keep the whole spatial zerotree quantization set into two descriptions. The frequency scalar quantization set Q is divided into two parts for two descriptions Q_1 and Q_2. In fact, the coding result can be controlled by the choice of the scalar quantization sets. More refined quantization step set will bring more effective results. Different frequency scalar quantization step sets are used for the two descriptions. Each of the set has its own special quantization steps which are different from the other one. The

relation of such two subsets must satisfy the following request.

$$Q_1 \cap Q_2 \neq \emptyset \quad \& \quad Q_1 \cup Q_2 = Q \tag{10}$$

3) Secondly, considering the computation complexity, two quantization step values are kept in each description. The original frequency scalar quantization step set contains three different values. The middle value of scalar quantization step set is kept in both descriptions. The smaller and the larger values are kept into the two different descriptions. It means that the original smaller and the middle values are kept in one description. The larger and the middle values are kept in the other description.

After the encoding process, two coding streams are sent to two separate channels for transmission and decoding. If only one of these streams is received, a simple reconstruction will be achieved. And if the two descriptions both are received, a better result can be given. Actually, when the two channels are received perfectly, we can combine the more effect block reconstruction from two descriptions to get a better decoder results. Here, we use a block by block comparison for getting a better result. And this comparison method is based on the directional zerotree's special structure. Experiment results of this new proposed algorithm are given in the next section.

4. **Main Results.** The 512 × 512 Lena gray image is used for the experiment here. And the biorthogonal 4/4 three-layer wavelet transform is implemented on the original information. Experiment results of the one and both two channels received conditions under different bit rates are shown in Table 1.

Table 1. Coding performance at different bit rates

PSNR (dB)	Bit rates			
	0.25bpp	0.5bpp	0.75bpp	1.0bpp
Side 1	29.32	30.95	32.54	33.48
Side 2	29.11	31.03	32.15	33.24
Center	31.75	33.28	34.74	36.79

Comparison between the classical embedded coding algorithms based two-channel MDC framework and ours is given to show the efficiency of our proposed algorithm. The comparison results of one and two descriptions received cases are shown in Figure 6. All results are achieved at the bit rates 0.5bpp. The compared pictures are the two-channel framework based on the odd-even estimation method. And the coding algorithm is the classical SPIHT algorithm.

As we can see from the results, our new proposed method has a much better performance at the same bit rates with the similar MDC framework than the other algorithm. The high encoding efficiency of the non-embedded algorithm used in our new MDC framework is the source of such a good performance.

The most important evaluation standard for the MDC frameworks is the performance under different packets losing conditions. Experimental results' comparison between ours and other typical algorithms under different packets losing conditions are given in Figure 7.

The SPIHT coding algorithm based MDC framework is used for comparison here. All the results are achieved at the bit rates 0.5bpp and the information is packed in the same way which means that information from different directions is packed into the same packet.

As we can see from the results shown in Figure 7, our algorithm performs better than the algorithm in reference [20] when the packets received percentages are lower than 80%.

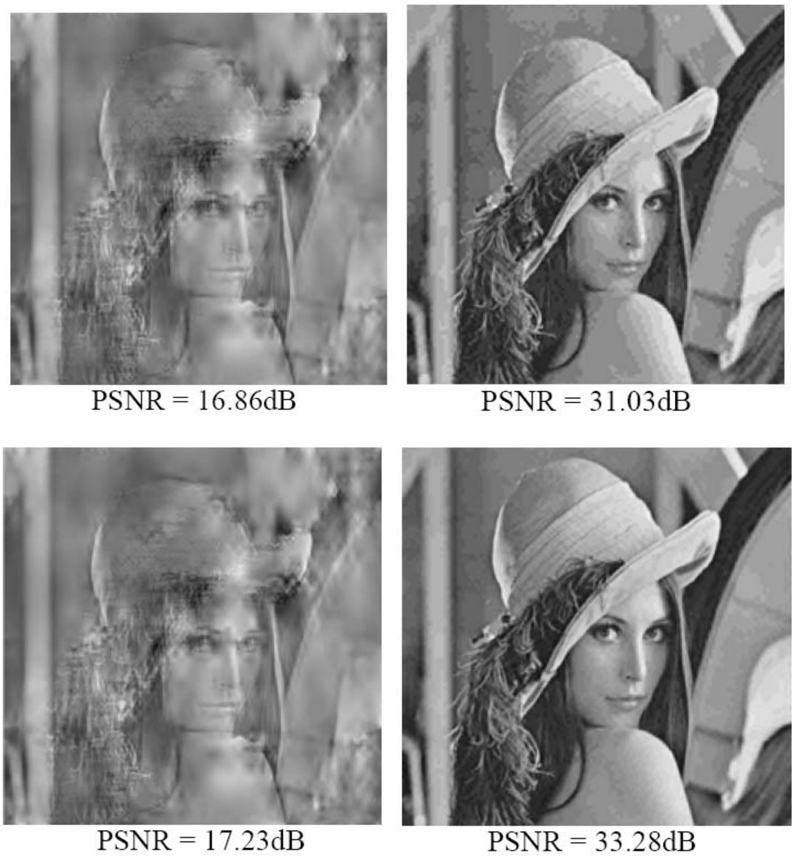


Figure 6. Compression between two algorithms

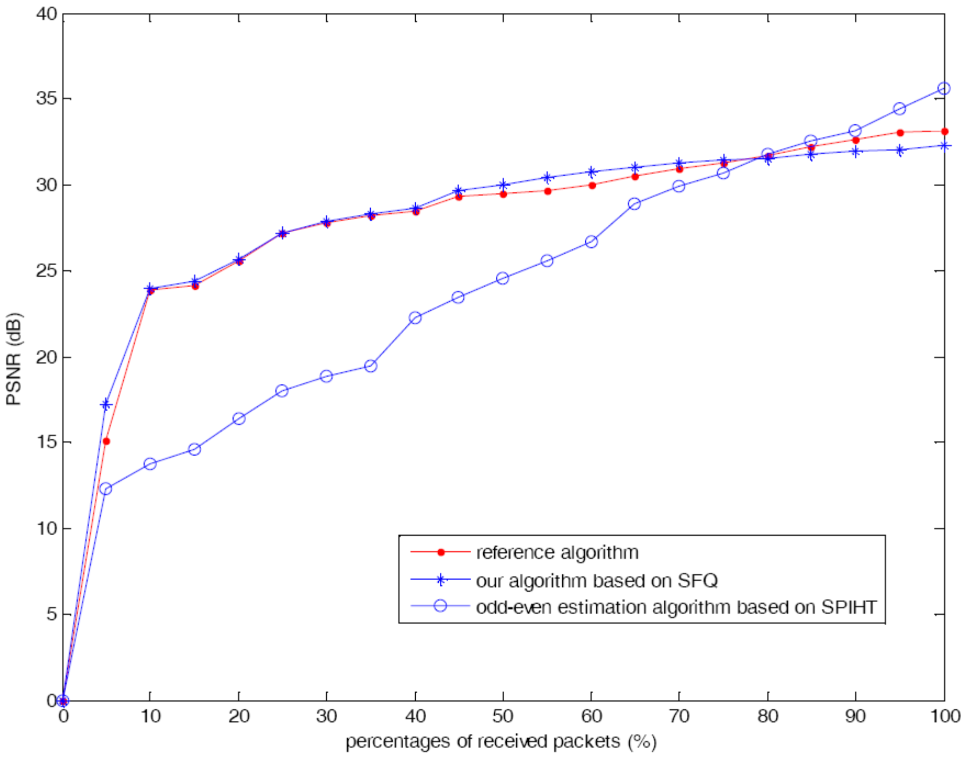


Figure 7. Comparison of PSNR performance

The weak performance around the higher packets received percentages is brought by the limitation of local optimal solution.

5. **Conclusions.** A new MDC framework based on the SFQ algorithm is introduced in this paper. Optimization set division method is used to form the two descriptions. Experimental results show the high efficiency of our proposed method. Though the result is good, the high computing complexity is its cost. To find the more efficient way to form the different descriptions is the future work under such a frame.

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