Multiple Description Transform Image Coder Using Correlating Transforms

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Abstract –*The objective of multiple description coding (MDC) is to represent a source into multiple descriptions such that various reconstruction qualities are obtained from different subsets of the descriptions. In this paper, we report an application of a proposed method for MDC to image coding. The method adds statistical redundancy to a set of data such that lost streams can be estimated from the received data. We employ a different way of forming the descriptions. The technique is shown to be more efficient and also overcomes the assumption that requires communication of the DC components reliably through other means.*

Keywords: *Joint source channel coding, multiple description coding, Image coding.*

Nomenclature

DC	Direct Current
DCT	Discrete Cosine Transform
JSCC	Joint Source Channel Coding
MDC	Multiple Description Coding
MDTC	Multiple Description Transform Coding
MSE	Mean Square Error
PSNR	Peak Signal to Noise Ratio
TCP	Transmission Control Protocol

I. Introduction

Source coding and channel coding are essential functions in any communication system. The source coding block is designed to remove as much redundancy as possible from the source while the channel coding block adds control redundancy to the compressed source. For practical and existing systems, these two blocks are separately optimized. This was motivated both by Shannon "separation theorem" [1] and by the conceptual simplicity of considering only one or the other. However it is well known that the Shannon theorem requires codes of infinite lengths (and hence infinite complexity and delay) for both source coder and channel coder.

The limitations of separate source and channel coding have lead to the problem of designing joint source-channel coding coders. JSC coding can lead to performance gains under complexity and/or delay constraints and offer robustness against channel variation.

Multiple description coding is a technique which can be considered a JSC code for erasure channels. It is recognized [2] as an effective method to protect multimedia information transmitted over networks subject to erasures. In the MDC approach, two or more correlated descriptions of the same data are generated which can be independently decoded, and yield mutually refinable information. Therefore, the quality of the recovered signal is dependent only on the number of received descriptions, and not on the specific loss pattern. Many methods have been proposed for the generation of multiple descriptions, among which MD scalar quantization [3], use of correlating transforms [4]-[10].

In this work, we are interested in the transmission of still images. Commonly, an image is communicated over the internet using a progressive coder with TCP, the standard protocol that controls the retransmission of lost packets. Progressive transmission works well when the packets are received in order without loss. But when there is a packet loss, the image reconstruction stalls until that particular packet is received which will result in a large period of latency. To cure this problem of latency, we need to have a transmission system robust to packet losses and able to reconstruct the image from packets received in any order.

In this paper, we propose the use of the method described in [5] for the case of four descriptions. We employ a different technique in forming the four packets of data. This technique shows a noticeable performance improvement with respect to the one used in [5]. We also show, that using this approach, we don't need to assume that the DC components are reliably communicated using other means.

II. Multiple Description Transform Coding

We propose to use the standard transform coding framework to realize the objective of MDTC. In conventional transform coding, the transform is used to decorrelate the input variables. Here we use a transform to introduce a controlled amount of correlation among the transformed coefficients. In other words, a block of N independent, zero-mean variables with different variances, is mapped to a block of N statistically

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correlated transform coefficients.

The forward transform with quantization stepsize Δ of a source vector x is implemented as:

1. $x = [x_1 \quad x_2 \quad . \quad . \quad x_n]^t$ (t stands for transposition) is uniformly quantized : $x_q = [x]_\Delta$
2. The vector $x_q = [x_{q1} \quad x_{q2} \quad . \quad . \quad x_{qn}]^t$ is transformed : $y = \hat{T}(x_q)$
3. The components of y are independently coded.

$\hat{T}$ is a discrete version of a continuous transform T. The derivation of $\hat{T}$ from T is by first factoring T into a product of upper and lower triangular matrices with unit diagonals $T = T_1 T_2 ... T_k$. The discrete version of the transform is then given by [4]:

$$\hat{T}(x) = \left[T_1 \left[T_2 ... \left[T_k x_q\right]_\Delta\right]_\Delta\right]_\Delta \qquad (1)$$

When all the components of $y = [y_1 \quad y_2 \quad . \quad . \quad y_n]^t$ are received, the reconstruction is obtained from the inverse transform. The distortion is precisely the quantization error from step 1. If some components of y are lost, they are estimated from the received components using the statistical correlation introduced by the transform $\hat{T}$. Consider $k > 0$ components of y are erased, the reconstruction procedure is as follow [6], [9]: Assume that $\tilde{y}_r = [y_1 \quad y_2 \quad . \quad . \quad y_{n-k}]^t$ are received and $\tilde{y}_{nr} = [y_{n\_k+1} \quad y_{n-k+2} \quad . \quad . \quad y_n]^t$ are lost. The vector y could be partitioned in "received" and "not received" components as $y = [\tilde{y}_r \quad \tilde{y}_{nr}]$. The minimum MSE estimate of x given $\tilde{y}_r$ is $E[x/\tilde{y}_r]$. Using the linearity of the expectation operator we have:

$$\begin{aligned} \hat{x} &= E[x/\tilde{y}_r] = E\left[T^{-1}Tx/\tilde{y}_r\right] = T^{-1}E[Tx/\tilde{y}_r] \\ &= T^{-1}E\left[\begin{bmatrix}\tilde{y}_r \\ \tilde{y}_{nr}\end{bmatrix}\Big/\tilde{y}_r\right] = T^{-1}\begin{bmatrix}\tilde{y}_r \\ E[\tilde{y}_{nr}/\tilde{y}_r]\end{bmatrix} \end{aligned} \qquad (2)$$

If the correlation matrix of y is portioned in a way compatible with the partition of y as

$$R_y = TR_x T^t = \begin{bmatrix} R_1 & B \\ B^t & R_2 \end{bmatrix} \qquad (3)$$

then it can be shown that $\tilde{y}_{nr}/\tilde{y}_r$ is Gaussian with mean $B^t R_1^{-1}\tilde{y}_r$. Thus $E[\tilde{y}_{nr}/\tilde{y}_r] = B^t R_1^{-1}\tilde{y}$ and

$$\hat{x} = T^{-1}\begin{bmatrix}\tilde{y}_r \\ B^t R_1^{-1}\tilde{y}\end{bmatrix} \qquad (4)$$

It is shown in [7] that for coding a two component vector source, where each is likely to fail, it is sufficient to consider transforms of the form

$$T_\alpha = \begin{bmatrix} \alpha & 1/2\alpha \\ -\alpha & 1/2\alpha \end{bmatrix}$$

This is used in [4] to build larger transforms; Figure 1 illustrates the case of 4 components (descriptions).

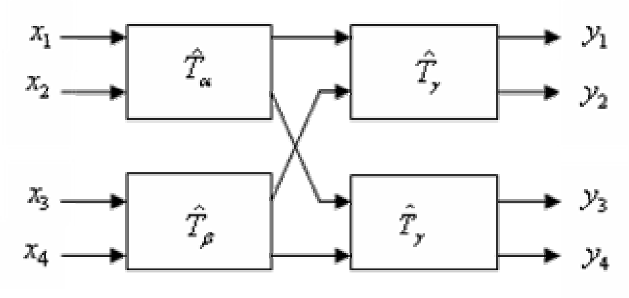

Fig. 1. Cascade structure for MDTC coding of four variables

III. Image Coding Using MDTC

We consider the case of four variables. This method is designed to operate on source vectors with uncorrelated components. Such a condition is obtained by forming vectors from DCT components. The coding process is implemented as follows:

1. The source image is transformed by an 8x8 DCT transformation.
2. The DCT coefficients are uniformly quantized.
3. The quantized DCT coefficients are split into 4 vectors (descriptions).
4. Correlating transform is applied to the 4 vectors.
5. Entropy coding is applied to each vector.

In step 3, we applied two techniques to create the four descriptions, and for each technique we considered two cases concerning the DC coefficients:

Technique1/case1: used in [5], where vectors are formed from quantized DCT coefficients separated to the maximum in frequency and space with the DC coefficients assumed to be communicated reliably by some other means. This method is referred to as MDTC_TEC1.

Technique1/case2: as in technique/case1 but here the DC coefficients are assumed to be transmitted along with the four packets of data.

The following example illustrates the procedure used in this technique to form the four vectors:

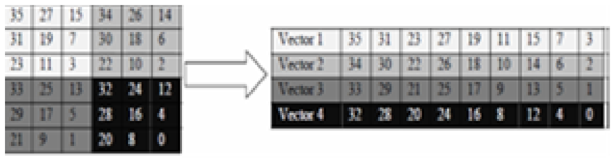

Fig. 2. Technique 1: description forming from 2D DCT matrix with block size of 6

Technique2/case1: quantized DCT coefficients at (odd row, odd column) are assigned to description 1; those at (odd row, even column) are assigned to description 2; those at (even row, odd column) are assigned to description 3; and those at (even row, even column) are assigned to description 4. The DC coefficients are assumed to be communicated reliably by some other

means. This technique is referred to as MDTC_TEC2.
Technique2/case2: akin to technique2/case1, but the DC coefficients are transmitted along with the four packets of data.

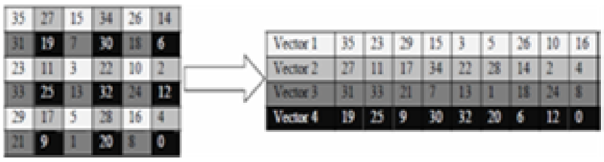

Fig. 3. Technique 2: description forming from 2D DCT matrix with block size of 6

Redundancy of 0.1 bit/sample [11] is evenly allocated to the four descriptions. The bit rate is the entropy estimated from the histograms.
Simulation results for the 512x512 ‘Boat’ and 512x512 ‘Goldhill’ images for both cases are respectively given in Fig. 4 and Fig. 5. In both figures the average PSNR is reported as a function of the bit rate for the case of one packet dropped. We can observe that the MDTC_TEC2 performs better than the MTDC_TEC1. Also it is worth noticing that our proposed technique is more robust than the other method especially when the DC coefficients are not transmitted reliably with some other means (i.e. they are being communicated with the four descriptions). The average performance gains amount to an interesting value [12] of nearly 6 dB and 3.5 dB for Goldhill and boat images respectively. For a qualitative comparison, we illustrate in figures 6 to 11 the subjective reconstruction quality of the boat and Goldhill images for the cases of one, two and three packets lost using the two techniques and assuming the two situations concerning the DC component. In each figure, (a) and (b) illustrate the quality that can be achieved using technique 1 and technique 2 respectively with DC coefficients communicated reliably with some other means, whereas (c) and (d) represent the obtained quality using technique 1 and technique 2 respectively with DC coefficients transmitted with the four data streams. It can be easily noticed that, using the new proposed coder MDTC_TEC2, the visual quality is significantly improved especially when the DC coefficients are being communicated with the four descriptions.

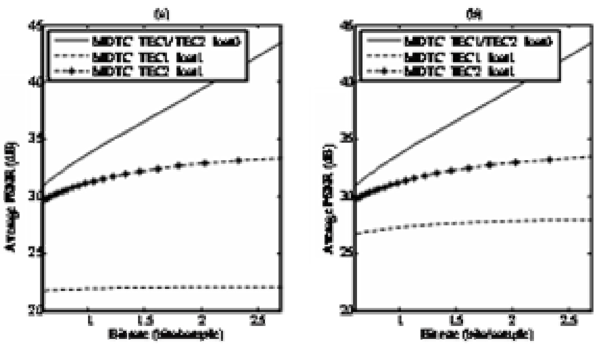

Fig. 4. Average PSNR versus bits per sample for Goldhill image. (a) DC coefficients transmitted with the four descriptions, (b) DC coefficients reliably communicated with some other means.

IV. Conclusion

In this paper, we have considered a MDTC coder for coding still images for the case of four descriptions. We have tested our proposed technique, employed in the creation of the four descriptions, on ‘boat’ and ‘Goldhill’ images. We have demonstrated through simulations that the performance of this method surpasses that of previously published methods, both visually and in terms of PSNR. In addition, the proposed approach cures the problem of the DC coefficients such that we don’t need to communicate them reliably by some other means.

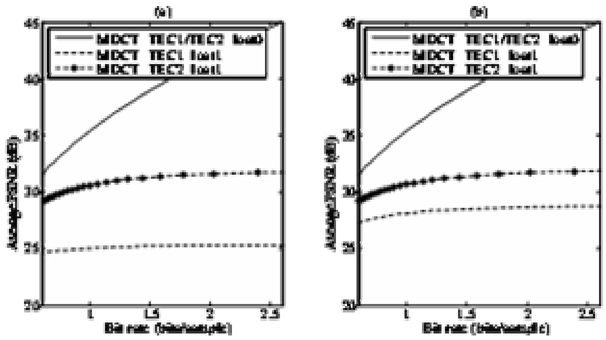

Fig. 5 Average PSNR versus bits per sample for boat image. (a) DC coefficients transmitted with the four descriptions, (b) DC coefficients reliably communicated with some other means

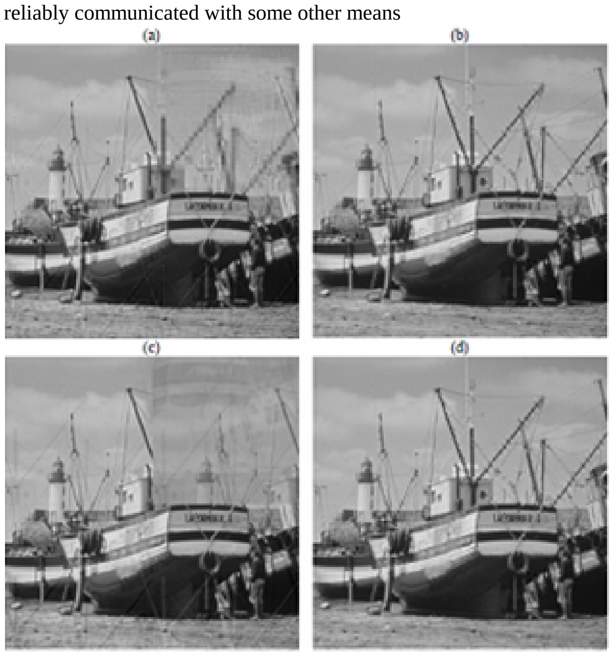

Fig. 6. Boat image reconstruction results with one packet lost, at 2 bits/sample. (a) MDTC_TEC1 with DC coefficients communicated reliably with some other means (PSNR = 28.78 dB); (b) MDTC_TEC2 with DC coefficients communicated reliably with some other means (PSNR = 31.97 dB); (c) MDTC_TEC1 with DC coefficients communicated with the four data streams (PSNR = 25.35 dB); (d) MDTC_TEC2 with DC coefficients communicated with the four data streams (PSNR = 31.86 dB).

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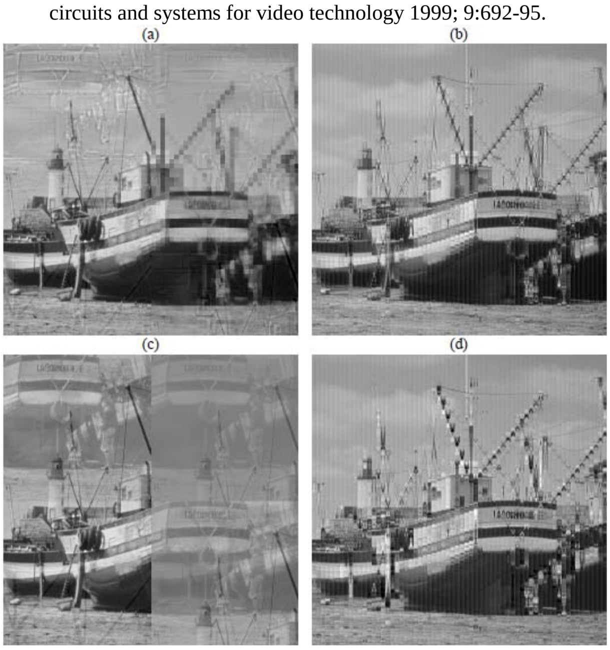

Fig. 7. Boat image reconstruction results with two packets lost, at 2 bits/sample. (a) MDTC_TEC1 with DC coefficients communicated reliably with some other means (PSNR = 25.25 dB); (b) MDTC_TEC2 with DC coefficients communicated reliably with some other means (PSNR = 24.53 dB); (c) MDTC_TEC1 with DC coefficients communicated with the four data streams (PSNR = 15.94 dB); (d) MDTC_TEC2 with DC coefficients communicated with the four data streams (PSNR = 21.54 dB).

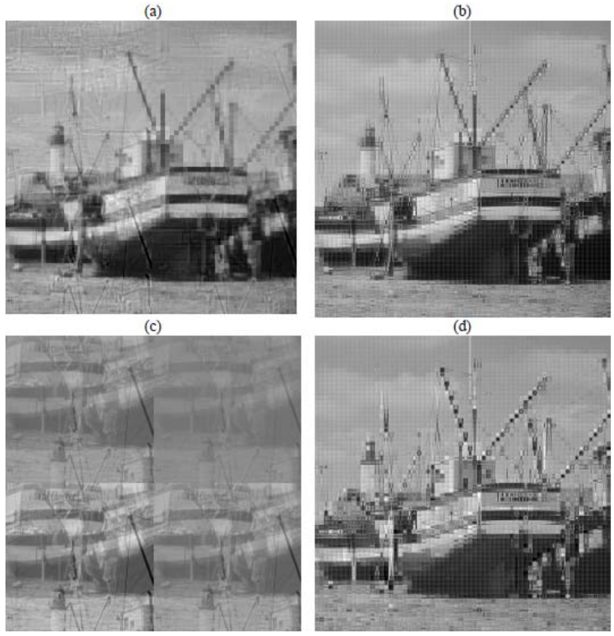

Fig. 8. Boat image reconstruction results with three packets lost, at 2 bits/sample. (a) MDTC_TEC1 with DC coefficients communicated reliably with some other means (PSNR = 23.60 dB); (b) MDTC_TEC2 with DC coefficients communicated reliably with some other means (PSNR = 22.41 dB); (c) MDTC_TEC1 with DC coefficients communicated with the four data streams (PSNR = 14.81 dB); (d) MDTC_TEC2 with DC coefficients communicated with the four data streams (PSNR = 19.72 dB).

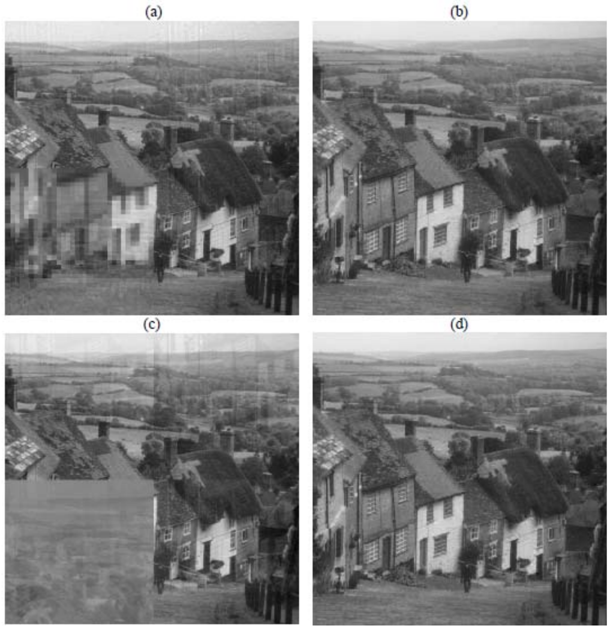

Fig. 9. Goldhill image reconstruction results with one packet lost, at 2 bits/sample. (a) MDTC_TEC1 with DC coefficients communicated reliably with some other means (PSNR = 28.03 dB); (b) MDTC_TEC2 with DC coefficients communicated reliably with some other means (PSNR = 33.68 dB); (c) MDTC_TEC1 with DC coefficients communicated with the four data streams (PSNR = 22.12 dB); (d) MDTC_TEC2 with DC coefficients communicated with the four data streams (PSNR = 33.60 dB).

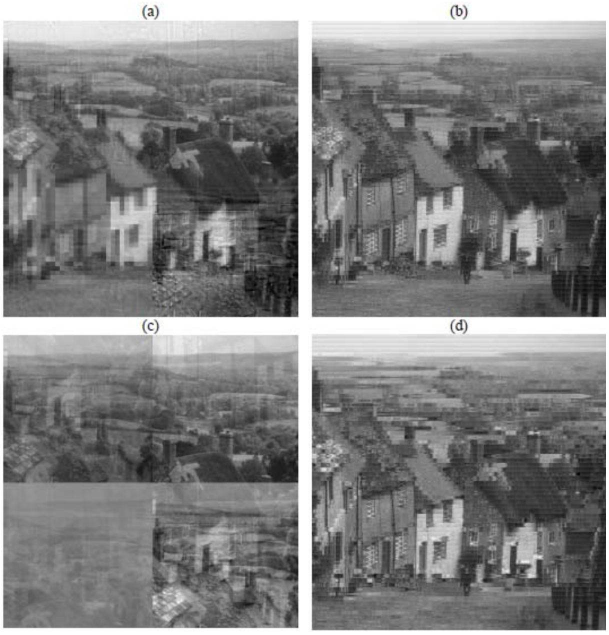

Fig. 10. Goldhill image reconstruction results with two packets lost, at 2 bits/sample. (a) MDTC_TEC1 with DC coefficients communicated reliably with some other means (PSNR = 25.45 dB); (b) MDTC_TEC2 with DC coefficients communicated reliably with some other means (PSNR = 26.31 dB); (c) MDTC_TEC1 with DC coefficients communicated with the four data streams (PSNR = 17.24 dB); (d) MDTC_TEC2 with DC coefficients communicated with the four data streams (PSNR = 23.32 dB).

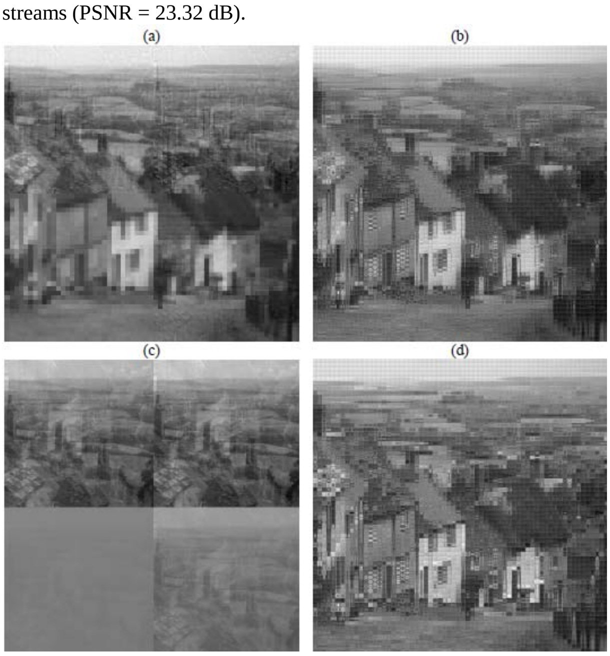

Fig. 11. Goldhill image reconstruction results with three packets lost, at 2 bits/sample. (a) MDTC_TEC1 with DC coefficients communicated reliably with some other means (PSNR = 24.74 dB); (b) MDTC_TEC2 with DC coefficients communicated reliably with some other means (PSNR = 23.88 dB); (c) MDTC_TEC1 with DC coefficients communicated with the four data streams (PSNR = 16.13 dB); (d) MDTC_TEC2 with DC coefficients communicated with the four data streams (PSNR = 21.32 dB).

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