PROGRESSIVE DCT BASED IMAGE CODEC USING STATISTICAL PARAMETERS

Pooneh Bagheri Zadeh, Tom Buggy
School of Engineering and Computing, Glasgow Caledonian University, 70 Cowcaddens Road, Glasgow,UK

Akbar Sheikh Akbari
Department of Electrical and Electronic Engineering, University of Bristol, Woodland Road, Bristol, UK

Keywords: Discrete cosine transform, image compression, perceptual weights, statistical parameters.

Abstract: This paper presents a novel progressive statistical and discrete cosine transform based image-coding scheme. The proposed coding scheme divides the input image into a number of non-overlapping pixel blocks. The coefficients in each block are then decorrelated into their spatial frequencies using a discrete cosine transform. Coefficients with the same spatial frequency at different blocks are put together to generate a number of matrices, where each matrix contains coefficients of a particular spatial frequency. The matrix containing DC coefficients is losslessly coded to preserve visually important information. Matrices, which consist of high frequency coefficients, are coded using a novel statistical encoder developed in this paper. Perceptual weights are used to regulate the threshold value required in the coding process of the high frequency matrices. The coded matrices generate a number of bitstreams, which are used for progressive image transmission. The proposed coding scheme, JPEG and JPEG2000 were applied to a number of test images. Results show that the proposed coding scheme outperforms JPEG and JPEG2000 subjectively and objectively at low compression ratios. Results also indicate that the decoded images using the proposed codec have superior subjective quality at high compression ratios compared to that of JPEG, while offering comparable results to that of JPEG2000.

1 INTRODUCTION

With advances in multimedia technologies, demands for transmission and storage of voluminous amounts of multimedia data have dramatically increased. In recent years wavelet based image coding schemes have achieved impressive success, mainly due to the novel approaches taking by these schemes in data organization and representation of wavelet-transformed coefficients Ostermann et al. (2004), Voukelatos and Soraghan (1997), Sheikh Akbari et al. (2004). Grgic, Grgic and Zovko-Cihlar (2001) has shown that discrete cosine transform (DCT) produces slightly better results than wavelets especially at low compression ratios while its computational complexity is less expensive than that of wavelets. A comparative study on wavelets and DCT reported by Xiong, Ramchandran and Orchard (1997) shows the main factors to distinguish image compression schemes are the way the transformed coefficients are rearranged, quantized and coded rather than the difference between the transforms used.

Statistical parameters of the image data have been used in a number of image compression techniques and offer promising visual quality especially at high compression ratios Chang and Chen (1993), while the application of statistical parameters of the transformed image data in image compression is less reported in the literature. Having knowledge of the statistical behaviour of the DCT coefficients plays an important role in designing an efficient compression algorithm. Several studies on the statistical distribution of the DCT coefficients have been reported in the literature Eude, Cherifi and Grisel (1994), Yovanof and Liu (1996) and Altunbasak and Kamaci (2004). In Yovanof and Liu (1996) the DCT coefficients were modelled using a Generalized Gaussian Function. The results showed that the high frequency and mid frequency DCT

Bagheri Zadeh P., Buggy T. and Sheikh Akbari A. (2008).
PROGRESSIVE DCT BASED IMAGE CODEC USING STATISTICAL PARAMETERS.
In *Proceedings of the Third International Conference on Computer Vision Theory and Applications*, pages 85-92
DOI: 10.5220/0001084800850092

coefficients are well approximated by the Generalized Gaussian Function while the low frequency and DC coefficient are well approximated by a mixture of several Generalized Gaussian Function. In Eude, Cherifi and Grisel (1994), the DCT coefficients were approximated by a mixture of Gaussian distribution model and based on this model a DCT-based compression technique was developed. This compression algorithm employs a quantization table that is a modification of the JPEG quantization table according to their distribution model. Results indicated superior visual quality in comparison to that of JPEG.

In this paper, a progressive statistical and DCT (SDCT) based image-coding scheme is presented. The proposed coding scheme divides the input image into a number of non-overlapping blocks and applies a DCT on coefficients in each block. The coefficients with the same frequency indices at different DCT blocks are grouped together and make a number of matrices. The matrix containing the DC coefficients is losslessly coded. The matrices containing high frequency coefficients are coded using a novel statistical encoder, which is developed in this paper. The proposed statistical encoder applies a hierarchical estimation algorithm to code the coefficients in each matrix. The hierarchical estimation algorithm assumes that the distributions of the coefficients in the matrices are Gaussian in some regions. A threshold on the variance of the coefficients is used to determine if it is possible to estimate the coefficients in the input matrix with the mean value of a single Gaussian distribution or it needs further dividing into four sub-blocks. This hierarchal algorithm is repeated until the distribution of the coefficients in all sub-blocks fulfils the above criteria. Finally, the mean value of the Gaussian distribution of each block is taken as an estimation value for all coefficients in that block. During the encoding process a quadtree-like binary map is generated to save a record of the hierarchical operation, which is used in decoding process. The rest of the paper is organized as follows: in Section 2 the proposed coding scheme is discussed; Section 3 explains the decoder; experimental results are presented at Section 4; and finally Section 5 concludes the paper.

2 PROGRESSIVE STATISTICAL AND DCT BASED IMAGE ENCODER

A block diagram of the Progressive Statistical Discrete Cosine Transform (SDCT) based image encoder is illustrated in Figure 1. A gray scale image is input to the encoder. The encoder divides the input image into a number of 8×8 non-overlapping pixel blocks called B_{11} to B_{nn} as shown in Figure 1(a). The coefficients in each block are then transformed into the frequency domain using a DCT as shown in Figure 1(b) where $A_{0\text{-}ij}$ to $A_{63\text{-}ij}$ are DCT transformed coefficients in the B_{ij} block. The coefficients with the same frequency indices at different blocks are then grouped together and generate 64 matrices called M_0 to M_{63}, where M_0 contains the DC coefficients and M_1 to M_{63} contain the AC coefficients from the lowest to the highest frequency respectively. Figure 1(c) shows one of these matrices (M_k), where $A_{k\text{-}11}$ to $A_{k\text{-}nn}$ in this matrix represent the coefficients with the same frequency index (k), which can take a value between 1 and 63, at different transformed blocks. In this figure, indices *11* to *nn* represent the position of the block that the coefficients belong to.

Figure 1(d) illustrates the encoding stage of the 64 matrices. The M_0, which contains most of the image energy, is losslessly coded, using lossless DPCM method. The M_1 to M_{63} matrices are coded individually using the following operations: (i) Coefficients in each matrix are first level shifted to have a minimum value (Min) of zero; (ii) the resulting coefficients are then coded using a novel statistical encoding algorithm, which is presented in Sub-section 2.2. The statistical encoder takes coefficients in each matrix and a threshold value (generated specifically for that matrix (detailed in Sub-section 2.1)), and performs the encoding process. The output of this encoder is a mean vector (**mv**), which carries the mean values, and a binary vector (**q**), which carries the quadtree-like data. (ii) Finally a multiplexor puts the encoded information together and generates a bitstream called BS_L, where L specifies the correspondent matrix, as shown in Figure 1d. The resulting bitstreams are transmitted from BS_0 to BS_{63} sequentially to perform progressive image transmission.

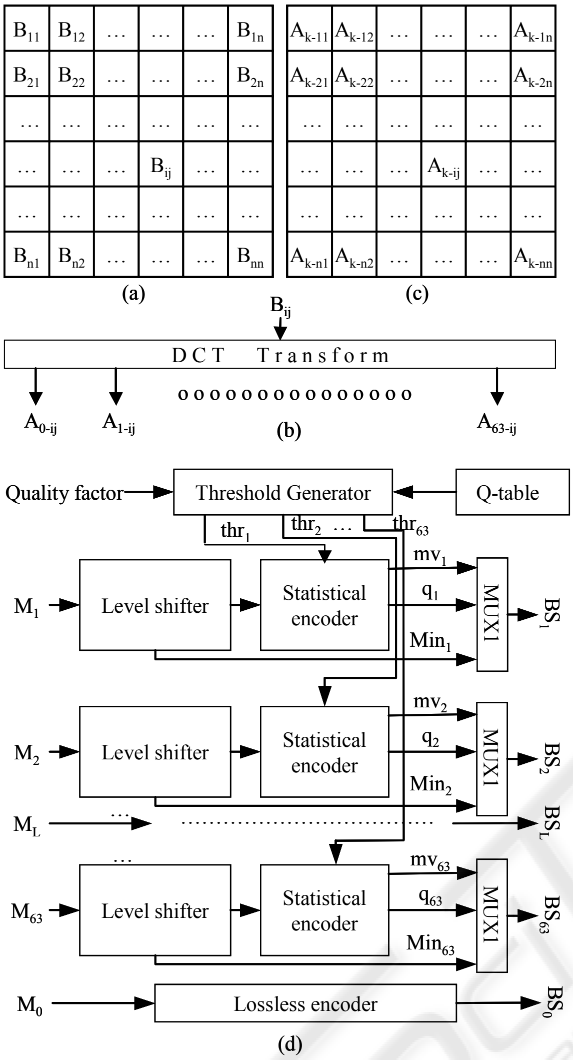

Figure 1: Statistical and DCT Based image encoder (a) non–overlapping blocks in an image (b) DCT transform of the coefficients in the block ij (c) organization of the coefficients in matrix M_K (d) encoding algorithm.

2.1 Threshold Generation

The threshold value for each matrix is generated using a uniform quality factor and its JPEG quantization step, which is derived from the JPEG quantization table and carries perceptual weight for that frequency band. The threshold values are calculated using the following empirical formula:

$$Threshold = (Q\_step \times Quality\_factor)^{1/4} \quad (1)$$

Where Q_step is its related JPEG quantization step, and the Quality_factor, which takes any positive values between 0 and 1000, controls the compression ratio. This empirical formula has been found to be appropriate for a wide range of test images, e.g. Lena, House, Elaine, Bee, Goldhill, peppers, Zelda, Café.

2.2 Statistical Encoder

The block diagram of the new statistical encoder is shown in Figure 2. The statistical encoder takes the coefficients of one of the high frequency matrices (M_1 to M_{63}) and a threshold value, generated specifically for that matrix (detailed in Sub-section 2.1), and performs the encoding process on it. For simplification, the input matrix in explanation of the encoder is called U. The encoding process for the input matrix U is as follows:

The encoder first defines two empty vectors called **mv** (mean value vector) and **q** (quadtree-like vector). It then calculates the variance (var) and the mean value (m) of the matrix U and compares the resulted variance value with the threshold value. If the variance is less than the threshold value, the matrix is coded by its mean value (m) and one bit binary data equal to 0, which are placed in the **mv** and **q** vectors, respectively. Otherwise one bit binary data equal to one is placed at the **q** vector and the size of the matrix is checked. If the size of the matrix is 2×2, the four coefficients of the matrix are scanned and placed in the **mv** vector and encoding process is finished by sending the mean value vector **mv** and the quadtree-like vector **q**. If the size of the matrix is greater than 2×2, the matrix U is divided into four equal non-overlapped blocks. These four blocks are then processed from left to right, as shown in Figure 2. For simplification, the continuation of the coding process of the first block, U_1, is discussed. This process is exactly repeated on the three other blocks.

Processing of the first block U_1 is described as follows: The variance (var_1) and the mean value (m_1) of the sub-matrix U_1 are first calculated and then the resulting variance value is compared with the input threshold value. If it is less than the threshold value, the calculated mean value (m_1) is concatenated to the mean value vector **mv** and one bit binary data equal to 0 is appended to the quadtree-like vector **q**. The encoding process of this sub-block is terminated at this stage. Otherwise, the size of the sub-block is checked. If it is 2×2, one bit binary data equal to 1 is appended to the current quadtree-like vector **q** and the four coefficients of the sub-block are scanned

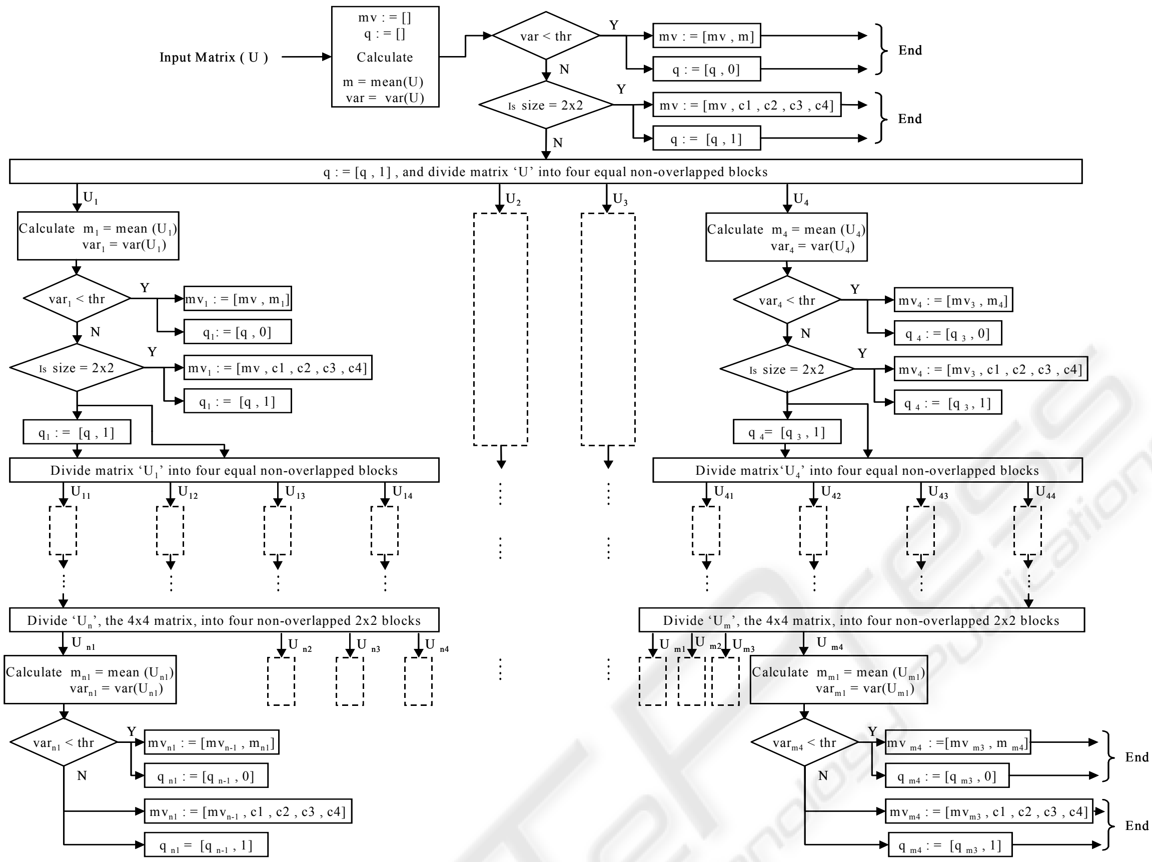

Figure 2: Block diagram of statistical encoder.

and concatenated to the **mv** vector and encoding process is ended for this sub-block. If its size is larger than 2×2, one bit binary data equal to 1 is concatenated to the current quadtree-like vector **q** and the sub-block U_1 is then divided into four equal non-overlapped blocks. These four new sub-blocks are named successor sub-blocks and are processed from left to right in the same way that their four ancestor sub-blocks were encoded. The above process is continued until whole successor blocks are encoded. When the encoding process is finished two vectors **mv** and **q** are passed to the output.

3 PROGRESSIVE STATISTICAL AND DCT BASED IMAGE DECODER

Figure 3 shows a block diagram of the progressive statistical and DCT based image decoder. The decoding process is started when the reception of the BS_0, which contain the DC coefficients of all transformed DCT blocks, is completed. The decoder then assumes that the information in the remaining matrices is zero and reconstructs the output image with the minimum quality using the received data. The decoding process is continued as follow: (i) it waits until the receiving data for the next matrix is completed; (ii) it assumes that data in the remaining matrices are zero and reconstructs the image using information in the received matrices; (iii) if the reception of the information for all matrices is not completed, it goes back to stage (i). This process is repeated until user terminates the process or all bitstreams are received and the image with the highest possible quality is reconstructed.

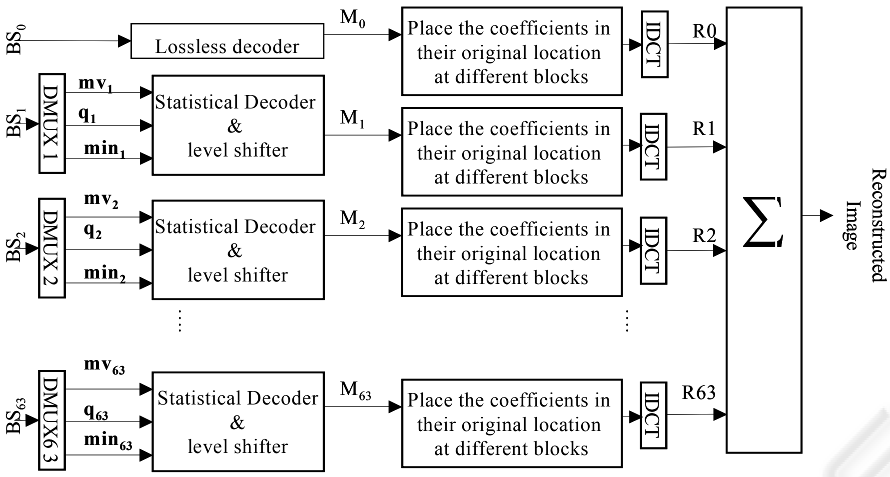

Figure 3: Block diagram of the progressive SDCT decoder.

4 EXPERIMENTAL RESULTS

In order to evaluate the performance of the new statistical and DCT (SDCT) based image-coding scheme, three Standard 8-bit greyscale images of resolution 512×512, 'Lena' 'Elaine' and 'House' were coded using JPEG, JPEG2000 and the proposed codec. The PSNR measurements for the encoded images using the three techniques at different compression ratios are shown in Figure 4. Results indicate that the proposed coding scheme outperforms JPEG and JPEG2000, objectively at low compression ratios while offers inferior performance at higher compression ratios. Consequently, to illustrate the visual quality obtained using the three coding scheme, the decoded 'Lena', 'Elaine' and 'House' images at compression ratio of 5, 15 and 40 are shown in Figure 5, 6 and 7, respectively. From Figure 5, it can be seen that all the decoded test images have very high visual quality at compression ratio of 5, where the decoded SDCT images have slightly higher visual quality than the decoded JPEG images and its quality is almost the same as that of JPEG2000. From Figure 6, which shows the test images at compression ratio of 15, some blocking artefacts are visible in the JPEG images, where SDCT images display higher visual quality to that of JPEG. The visual quality of the JPEG2000 images is slightly higher than that of SDCT. From Figure 7, which illustrate the test images at compression ratio of 40,it is observed that the JPEG images exhibit severe blocking artefacts, which limits the application of this codec in coding images at high compression ratios while the SDCT images contain moderate blocking artefacts. From this figure, it is clear that SDCT offers comparable visual quality to that of JPEG2000.

Therefore, it can be concluded that the SDCT techniques offers superior visual quality to that of JPEG at all compression ratios. This superiority does not come without a price. The computational complexity of the proposed codec seems to be higher than that of JPEG but we have not done any measurements on the computational cost. In the proposed codec the DCT transformed coefficients are first distributed among 64 matrices and then each matrix is coded using the statistical encoder while in JPEG the transformed coefficients are first quantized and then entropy coded. It is also concluded that SDCT image codec gives comparable visual quality to that of JPEG2000 at compression ratios below 30, while it offers an acceptable visual quality at higher compression. The SDCT image codec offers the following advantages:

(i) Its architecture facilitates parallel implementation, as the matrices could be coded independently.
(ii) Its bitstream is efficient for unequal error protection, which gives higher performance when transmitting in noisy environments.

5 CONCLUSIONS

In this paper a new progressive statistical and DCT based image-coding scheme was developed. It divides the input image into a number of non-overlapping pixel blocks. The blocks were then decorrelated using a DCT transform. The coefficients with the same frequency index from the

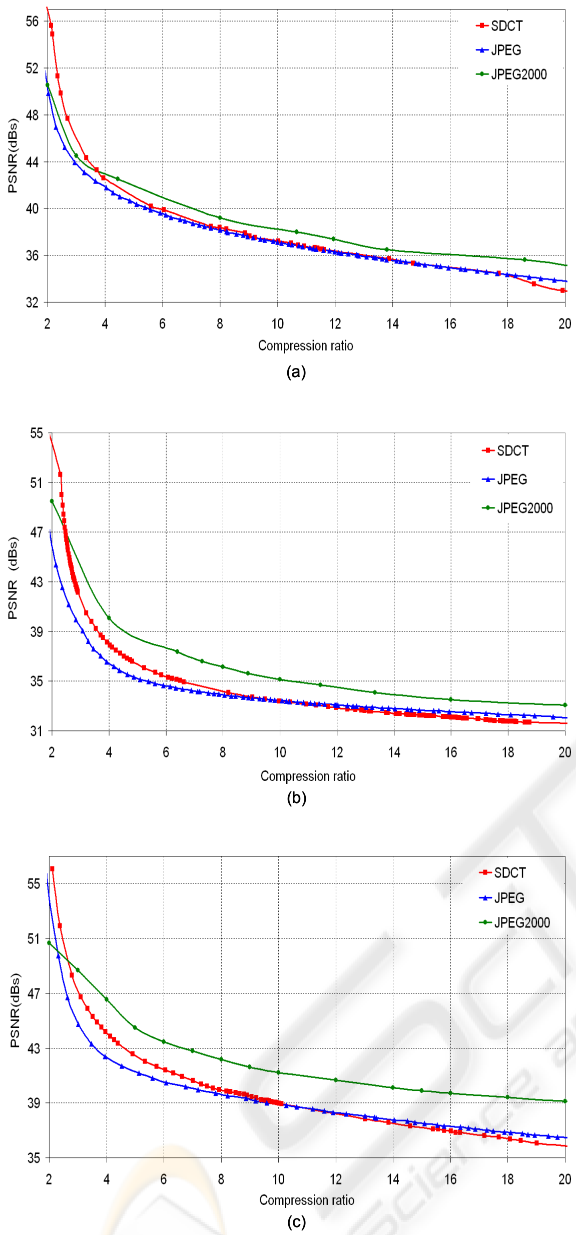

Figure 4: Coding performance of the SDCT, JPEG and JPEG2000 image codecs: (a) Lena, (b) Elaine and (c) House.

transformed blocks were put together and generate a number of matrices. The matrix contains DC coefficients was losslessly coded. The remaining matrices were coded using a novel statistical encoder. The statistical encoder estimates the input matrices with the mean value of a number of 2D Gaussian distribution. Results shown that the proposed codec outperforms JPEG subjectively at all compression ratios. The results indicated that the SDCT offer comparable subjective quality to JPEG2000 at medium to low compression ratios.

REFERENCES

Ostermann, J., Bormans, J., List, P., Marpe, D., Narroschke, M., Pereira, F., Stockhammer, T. & Wedi, T., 2004, 'Video coding with H.264/AVC: Tools, Performance, and Complexity', *IEEE Circuits and System Magazine,* vol.4, pp.7-28.

Voukelatos, S. P. & Soraghan, J. J., 1997, ' Very Low Bit Rate Colour Video Coding Using Adaptive Subband Vector Quantization with Dynamic Bit Allocation', *IEEE Transaction on Circuits and System for Video Technology*, vol. 7, no. 2, pp. 424-428.

Sheikh Akbari, A., Bagheri Zadeh, P., Cochrane, E. & Soraghan, J.J., 2004, 'Wavelet-based video codec using Human Visual System Coefficients for 3G mobiles', *12th European Signal Processing Conference (EUSIPCO 2004)*, Vienna, Austria.

Grgic, S., Grgic, M. & Zovko-Cihlar, B., 2001, 'Performance Analysis of Image Compression using Wavelets', *IEEE Transaction On Industrial Electronic*, vol. 48, no. 3, pp. 682 - 695.

Xiong, Z., Ramchandran, K. & Orchard, M., 1997, 'Space-frequency quantization for wavelet image coding', *IEEE Transaction on Image Processing*, vol.6, no.5, pp. 677–693.

Chang, R. F. & Chen, W. T., 1993, 'Image Coding Using Variable – Rate Side Match Finite - State Vector Quantization', *IEEE Transaction on Image Processing,* vol. 2, no. 1,pp. 104-108 .

Eude, T., Cherifi, H. & Grisel R., 1994, 'Statistical distribution of DCT coefficients and their application to an adaptive compression algorithm' *IEEE International Conference TENCON1994*, pp. 427-430.

Yovanof, G.S. & Liu, S., 1996, 'Statistical analysis of the DCT coefficients and their quantization error', *Thirtieth Asilomar Conference on Signals, Systems and Computers*, pp. 601-605.

Altunbasak, Y. & Kamaci, N., 2004, 'An Analysis Of The DCT Coefficient Distribution with The H.264 Video Coder', *ICASSP2004*, pp.178-180.

Figure 5: Coding quality performance of (a) SDCT (b) JPEG and (c) JPEG2000 codecs for 'Lena', 'Elaine' and 'House' test images at compression ratio of 5.

Figure 6: Coding quality performance of (a) SDCT (b) JPEG and (c) JPEG2000 codecs for 'Lena', 'Elaine' and 'House' test images at compression ratio of 15.

Figure 7: Coding quality performance of (a) SDCT (b) JPEG and (c) JPEG2000 codecs for 'Lena', 'Elaine' and 'House' test images at compression ratio of 40.