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Use of Fuzzy Edge Image in Block Truncation Coding for Image Compression

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***Abstract*—**An image compression method has been developed using fuzzy edge image utilizing the basic Block Truncation Coding (BTC) algorithm. The fuzzy edge image has been validated with classical edge detectors on the basis of the results of the well-known Canny edge detector prior to applying to the proposed method. The bit plane generated by the conventional BTC method is replaced with the fuzzy bit plane generated by the logical OR operation between the fuzzy edge image and the corresponding conventional BTC bit plane. The input image is encoded with the block mean and standard deviation and the fuzzy bit plane. The proposed method has been tested with test images of 8 bits/pixel and size 512×512 and found to be superior with better Peak Signal to Noise Ratio (PSNR) when compared to the conventional BTC, and adaptive bit plane selection BTC (ABTC) methods. The raggedness and jagged appearance, and the ringing artifacts at sharp edges are greatly reduced in reconstructed images by the proposed method with the fuzzy bit plane.

***Keywords*—**Image compression, Edge detection, Ground truth image, Peak signal to noise ratio

I. Introduction

DIGITAL images are widely used in a number of applications. It is seen that uncompressed digital images would need larger storage capacity and wider transmission bandwidth for effective utilization of picture information in modern applications. Hence efficient image compression solutions are becoming more critical with the recent growth of data intensive, multimedia-based web applications. Consequently image data compression has become an important area of research in the field of image processing for transmission and storage of image data. Reconstruction of images back to the original from the compressed image with minimum loss is the key issue in these applications. In order to obtain high compression rates in image coding, it is necessary to remove as much redundancy without loosing the image quality.

The process of edge detection reduces an image to its edge details that are often used in subsequent image processing applications, such as segmentation, identification of objects in scenes, feature extraction, and image compression. As edges can provide an efficient way for image representation, edge based compression techniques become very useful. Several works on edge-based image compression have been reported in literature. Graham [1] considers an image as being composed of low and high frequency parts, which are encoded separately. The high frequency part corresponds to contours in the image, and the low frequency part corresponds to smooth areas between contours. Kocher and Kunt [2] use region growing to segment the image into regions. The texture of each of these regions is encoded separately. Carlsson [3] proposes a sketch-based coding scheme for gray level images. Cheng and Tsai [4] propose an algorithm for image compression based on the application of the moment-preserving edge detection. The algorithm is computationally faster as it offers simple analytical formulae to compute the parameters of the edge feature in an image block. Reconstructed images are of good quality in accordance with human perception. Desai *et al.* [5] propose an edge and mean based compression algorithm that produces good quality images at very low bit rates. The algorithm represents the image in terms of its binary edge map, mean information, and the intensity information on both sides of the edges. Aggoun and Mabrouk [6] propose an image compression algorithm based on local edge detection to improve the bit rate of the conventional Block Truncation Coding (BTC) algorithm. The algorithm classifies image into visually active and visually continuous blocks, which are then coded individually. Han and Lin [7] propose a method for edge detection and image compression of bi-level error-diffused images. The technique is less complex and computationally fast. Neves and Mendonca [8] present an image compression technique that encodes edges and textures separately using the wavelet transform. Ryu *et al.* [9] suggest a self-organized edge detection scheme for image compression. Yang and Tsai [10] propose an adaptive bit plane selection based BTC (ABTC) method by using a set of predefined line and edge bit planes. Experimental results show that the proposed approach is effective in preserving reconstructed image quality and gaining reasonable lower bit rates. All these approaches put emphasis on edge extraction and coding, showing edge-based compression techniques are effective in producing good quality reconstructed images at lower bit rates.

Since the edge information is of primary importance in visual perception, we propose a fuzzy edge image based

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image compression method utilizing the basic conventional BTC method. This method has demonstrated in producing perceptually high quality reconstructed images with high PSNR values. The BTC is a fast, simple algorithm used for coding images at good quality and at low to moderate compression ratios. The basic algorithm of BTC was developed in 1979 by Delp and Mitchell [11], by incorporating ideas relative to how one could exploit statistical moments in the context of image compression. Since its introduction, the BTC algorithm has been modified in various ways and several different basic algorithms under the generic name BTC have been appeared in literature [12]-[14]. All these BTC algorithms are simple and computationally fast. In the proposed work, the existing conventional BTC algorithm has been modified using fuzzy edge image and a new method for image data compression based on fuzzy edge image is developed.

II. METHODOLOGY

The BTC is a two level non-parametric binary encoder based on moment preserving quantization that adapts to the local properties of the image. The input image is partitioned into non-overlapping 4×4 pixel blocks and coded individually. The algorithm preserves the first two sample moments, mean and standard deviation of each pixel block. Each 4×4 block is coded by the values of block mean and block standard deviation, together with the 4×4 bit plane consisting of 0s and 1s. The bit rate for basic BTC is 2 bits/pixel. Since the BTC produces a bitmap to represent a block, it could be considered as a binary pattern image coding method. The thresholding process makes it possible to reproduce sharp edges with high fidelity. However, the method produces ragged edges in the reconstructed images. Also due to insufficient quantization levels, anti-aliasing effects have been removed from the reconstructed images and sharp edges between contrasting pixels present a jagged appearance. In the proposed method, edge image obtained by Competitive Fuzzy Edge Detection (CFED) algorithm [15] is used in place of the bit plane generated by the conventional BTC. It will reduce the raggedness and jagged appearance in edges in the reconstructed image, and also reduce the Root Mean Square Error (RMSE) in the block quantization process. Similar to the conventional BTC, the proposed method uses a one bit nonparametric quantizer adaptive over the local regions of the image. The quantizer also preserves local statistics of the image.

A. Edge Image

Edge detection is one of the important topics in image processing and machine vision. It has been broadly covered and documented since the early stage of image processing studies. Its importance arises from the fact that edges are considered as important features for analyzing the most important information contained in images. An edge is characterized by significant variation in gray levels indicating the boundary between two regions in an image, curved or straight boundaries. Many classical edge detectors such as Sobel, Prewitt, Laplacian, and Canny edge detectors are available in literature [16]. Some of the problems associated with these methods are large volume of computation, sensitivity to noise, and thicker lines. Fuzzy logic based edge detection schemes are also reported in literature [17]-[18], the performance of these is somewhat similar to other methods but the speed is significantly faster.

The edge image proposed for use in this work is obtained from the CFED algorithm proposed by Liang and Looney [15]. The algorithm detects the edge pixels first, then competitive rules are applied for thinning the ridges, and finally single and double pixel noise specks are removed. For each pixel in an input image that is not on the outer boundary of the image, a four dimensional feature vector **x** = (d1,d2,d3,d4) is computed, where d1, d2, d3, and d4 are the sum of the bi-directional gray level differences between the central pixel and its neighbours for a 3×3 neighbourhood in the four directions, 0^o, 45^o, 90^o, and 135^o, respectively. The fuzzy classifier that accepts the feature vectors as the inputs and differentiates pixels into four edge classes, a background class, and a speckle edge class (noisy pixel edge class). The six classes have summed magnitude differences in the four directions, which could be low or high set by the user depend on the edge contrast and sensitivity desired. These values are the respective centers of the six classes. The classification is done by putting the feature vector **x** for each pixel through each of the six membership functions to obtain their fuzzy truths of memberships in one of the corresponding six classes. The largest fuzzy truth determines the class membership. It follows thinning of edges and removal of noisy edges by applying competitive rules to each edge pixel.

To evaluate the performance of the CFED algorithm, the quality of the edge image obtained by the algorithm has been compared with an ideal edge image, called the ground truth (GT) image. The GT image is generally obtained by manually defining the position of ideal edges and areas of interest in the original image. Since GT image is difficult to obtain for most images, here comparisons are made with the edge image from the most popular Canny edge detector based on the distortion metrics, namely Peak Signal to Noise Ratio (PSNR) and Figure of Merit (FOM) [19]. The distortion metrics are used to evaluate the similarity between two images. They measure the difference between the pixels corresponding to every position of the ideal edge image and actual edge image. The PSNR of two images, say, f (actual edge image) and g (ideal edge image) of dimensions X×Y is :

$$PSNR(dB) = 10\log_{10}\frac{\max_{x,y} f^2(x,y)}{\frac{1}{XY}\sum_{x=1}^{X}\sum_{y=1}^{Y}\left[f(x,y)-g(x,y)\right]^2} \quad (1)$$

The distortion metric, FOM is a widely used discrepancy measure for edge images and it is given by:

$$FOM = \frac{1}{I_N} \sum_{i=1}^{I_A} \frac{1}{1 + a.d^2(i)} \quad (2)$$

where $I_N = \max(I_I, I_A)$, and I_I and I_A represent the number of ideal and actual edge pixels, a is a scaling constant (usually, a = 1/9), and d(i) is the separation distance between an actual edge pixel i and its correct position in the ideal edge image.

B. Proposed Compression Method

For each input image block, the proposed method follows the steps of the conventional BTC algorithm except the bit plane is replaced with the fuzzy edge image. The input image is first divided into non-overlapping blocks of size n×n, (Here, we take n = 4). Let $m = n^2$ and $X_1, X_2, \ldots, X_m$ be the pixels values in a block of the original image. The block first and second sample moments of X_i pixels are computed by:

$$Mean, \bar{X} = \frac{1}{m} \sum_{i=1}^{m} X_i \quad (3)$$

$$Standard\ deviation, \bar{\sigma} = \left[\frac{1}{m} \sum_{i=1}^{m} (X_i - \bar{X})^2 \right]^{1/2} \quad (4)$$

The bit plane block with values 1s and 0s is generated by the one bit non-parametric binary encoder defined by:

$$\left. \begin{array}{l} output, b = 1 \quad if\ X_i \geq X_{th} \\ \qquad a = 0 \quad if\ X_i < X_{th} \end{array} \right\} \quad (5)$$

where X_{th} is the threshold and is taken as the mean of the block $\bar{X}$. The fuzzy edge image of the input image is obtained by the CFED algorithm and then it is partitioned into blocks of size 4×4. The logical OR operation is then performed between each edge block and the corresponding bit plane block. The OR operation produces a logical bit block that is of the same size as the input blocks and has a 1 at locations where either operand is a logical 1, or if they both are logical 1s; and 0s elsewhere. Each input image block is finally coded by the values of the mean, the standard deviation, and the logical bit block. So the compressed image data contains mean and standard deviation of all the 4×4 blocks and the logical bit block. Each input block is transmitted as logical bit block along with quantized information on the $\bar{X}$ and $\bar{\sigma}$.

At the receiver end, each logical bit block is reconstructed such that $\bar{X}$ and $\bar{\sigma}$ are preserved. For each pixel with value X_i, the output levels a and b are computed by:

$$a = \bar{X} - \bar{\sigma}\sqrt{\frac{q}{m-q}} \quad (6)$$

$$b = \bar{X} + \bar{\sigma}\sqrt{\frac{m-q}{q}} \quad (7)$$

where q is the number of pixels with value 1 in each logical bit block.

Each image block is reconstructed by calculating a and b using (6) and (7) and assigning these values to pixels in accordance with 0s and 1s in the logical bit block.

In the logical bit blocks there can be blocks with all the values either 0 or 1, such blocks are visually continuous indicating no edges in them. The sample mean is used to represent that block. So while reconstructing the image, such blocks are given a reconstruction value equal to the mean. In the proposed method, the compressed image is described by the values of block mean $\bar{X}$, block standard deviation $\bar{\sigma}$, and an n×n bit block consisting of 0s and 1s. Assigning 8 bits to each of $\bar{X}$ and $\bar{\sigma}$, and 16 bits to bit block results in a data rate of 2 bits/pixel. Thus the bit rate obtained for the proposed method is the same as the conventional BTC.

III. RESULTS AND DISCUSSIONS

It is obvious that when we combine edge detection with image compression for image transmission and storage, there will be loss of information in the reconstructed image when compared with original image. This loss can be due to both the stages of edge detection and compression. Accordingly, if it is required to obtain a scheme of image compression with minimum loss, it is necessary to evaluate the effectiveness or performance of the scheme of edge detection-compression-reconstruction technique. Due to the absence of a unified mathematical theory for the analysis, it has been done through an extensive computer simulation. In order to build the necessary insight into each of the stages, each one has been considered as separate problems and subsequently combined them together to obtain the proposed scheme. The results of these investigations are discussed in this section.

The performance of the proposed system has been evaluated for a set of six gray scale images, namely, Cameraman, Lena, Peppers, Jet, Mandrill, and Tank, each of size 512×512. The CFED algorithm is compared with three classical edge detectors – Sobel, Laplacian, and Prewitt on the basis of the results of the most popular Canny edge detector. Table I shows that FOM is larger for the CFED algorithm in comparison with the classical edge detectors with a maximum of 0.9 for almost all the test images. For an ideal edge detector the FOM should be 1 and provide a high PSNR value. The number of edge pixels detected by CFED algorithm is given in table I, which is larger than those by the classical edge detectors including the Canny edge detector. It indicates that the CFED is capable to detect majority of the edge pixels in the input image as seen in Fig. 1 for the sample edge image of cameraman. It is also observed that the Canny edge detector outperforms the other classical edge detectors with large number of edge pixels for all the test images. The FOM for the classical edge detectors is much less, whereas the PSNR values are slightly less than that of the CFED algorithm. Thus the results demonstrate that the CFED algorithm has comparable performance both in detecting edge pixels and providing better visual quality edge image than the Canny edge detector.

TABLE I
PERFORMANCE OF COMPETITIVE FUZZY EDGE DETECTOR AND CLASSICAL EDGE DETECTORS WITH CANNY EDGE IMAGE AS THE GROUND TRUTH (GT) IMAGE

Image	CFED+			Sobel			Laplacian			Prewitt			Canny
	FOM*	No. of edge pixel	PSNR&	FOM*	No. of edge pixel	PSNR&	FOM*	No. of edge pixel	PSNR&	FOM*	No. of edge pixel	PSNR&	No. of edge pixel
Cameraman	0.82	20483	45.97	0.28	6379	43.42	0.59	13582	45.92	0.28	6383	43.42	18712
Lena	0.90	18869	46.25	0.40	8254	45.00	0.64	13208	46.17	0.40	8191	45.00	18427
Peppers	0.90	20946	46.67	0.31	6245	44.04	0.53	10573	45.45	0.31	6217	44.06	18056
Jet	0.90	35699	48.52	0.41	8726	45.45	0.68	14205	46.25	0.41	8702	45.47	18907
Mandrill	0.90	90719	47.90	0.27	12620	43.15	0.65	30478	46.28	0.27	12376	43.11	41892
Tank	0.90	50250	46.87	0.19	9233	41.80	0.54	25084	45.25	0.19	9181	41.78	41790

+ : Competitive fuzzy edge detector, * : Figure of merit, & : Peak signal to noise ratio


original (a) (b)
(c) (d) (e)

Fig. 1 Edge image of Cameraman by (a) CFED (b) Canny (c) Sobel (d) Laplacian, and (e) Prewitt operators.

To evaluate the performance of the proposed method, a criterion called the average bit plane replacement error (ABPRE) is used, which is described in [10]. The fuzzy edge image generated by the CFED algorithm replaces the bit plane formed by the conventional BTC method. Then the bit difference (BD) between the two is computed for image block A_j as follows:

$$BD_j = \sum_{x=1}^{4}\sum_{y=1}^{4}\left|a'_j(x,y) - a_j(x,y)\right| \qquad (8)$$

where $a'_j(x,y)$ is the fuzzy edge image for block A_j, and $a_j(x,y)$ is the bit plane for block A_j. Then the bit plane replacement error for the block A_j is calculated as follows:

$$BPRE_j = \begin{cases} 1, & if\ BD_j > 4 \\ 0, & otherwise \end{cases} \qquad (9)$$

When $BPRE_j$ is set to 1, it means that when $BD_j > 4$, the bit plane replacement is unsuitable and it produces notable distortion in the reconstructed images [10]. Then the ABPRE of an input image is determined as follows:

$$ABPRE = \frac{1}{B}\sum_{j=1}^{B} BPRE_j \quad (10)$$

where B is the number of blocks in the input image.

The error metrics RMSE and PSNR are also used to evaluate the performance of the proposed method. They are defined as follows:

$$RMSE = \left[\frac{1}{XY}\sum_{x=1}^{X}\sum_{y=1}^{Y}\left[I(x,y) - I'(x,y)\right]^2\right]^{1/2} \quad (11)$$

$$PSNR(dB) = 10\log_{10}\frac{\max_{x,y} I^2(x,y)}{\frac{1}{XY}\sum_{x=1}^{X}\sum_{y=1}^{Y}\left[I(x,y) - I'(x,y)\right]^2} \quad (12)$$

where $I(x,y)$ is the original image, $I'(x,y)$ is the reconstructed image, and $X \times Y$ is the dimensions of the images. A lower value of RMSE means lesser error in the reconstruction, and as seen from the inverse relation between the RMSE and PSNR, this translates to a high value of PSNR. Logically, a higher value of PSNR is preferable because of the higher signal to noise ratio. Here, the signal is the original image and the noise is the error in reconstruction. So a compression method having lower RMSE and corresponding high PSNR values could be recognized as a better scheme.

Table II shows the ABPRE values of applying the proposed method to the test images. In the proposed method, both the fuzzy and canny edge images are used. A smaller value of ABPRE indicates that the bit plane replacement causes less error and it is necessitated in order to minimize errors and distortions in reconstructed images. From table II, it can be seen that the ABPRE values of using both the fuzzy and Canny logical bit blocks are smaller than the values of their corresponding edge images. This shows both the fuzzy and Canny logical bit blocks are visually almost identical to the bit plane generated by the conventional BTC method.

TABLE II
ABPRE VALUES OF APPLYING THE PROPOSED COMPRESSION METHOD TO THE TEST IMAGES

Image	CFED#	FEOBP@	Canny	CEOBP+
Cameraman	0.8694	0.0197	0.8834	0.0081
Lena	0.9199	0.0322	0.9307	0.0070
Peppers	0.9301	0.0372	0.9368	0.0015
Jet	0.8872	0.0828	0.9208	0.0035
Mandrill	0.6143	0.1505	0.9318	0.0253
Tank	0.9048	0.0889	0.9299	0.0146

: Competitive fuzzy edge detector, @ : Fuzzy edge ORed with bit plane (fuzzy logical bit block), + : Canny edge ORed with bit plane (Canny logical bit block)

Both the fuzzy and Canny edge images and the corresponding bit blocks generated by logical OR operation with the bit plane blocks by the conventional BTC are used in the experiments. For comparison, the ABTC [10] and conventional BTC [11] methods are also implemented. Table III shows the performance results of the images decoded by the proposed method, whereas the results of the ABTC and conventional BTC are given in table IV. The performance of the proposed method with the use of fuzzy logical bit block is better with lower RMSE and higher PSNR values compared to the method with the Canny logical bit block. Also, in comparison with the Canny edge image used in the proposed method, the method with the fuzzy edge image performs better (table III). For the ABTC method, in all the four sets of predefined bit planes, the set with 16 predefined bit planes performs better with slightly higher PSNR values for most of the test images (table IV). For the sample test image of cameraman, the clustered column chart shown in Fig. 2 compares the values of RMSE and PSNR for the proposed and the other methods. The RMSE values are less for the proposed method with the use of fuzzy logical bit block considering all the test results (tables III & IV). Considering all the test images, the average improvements in PSNR of the proposed method with fuzzy logical bit block compared to ABTC with 16 predefined bit planes and conventional BTC are 1.82 and 0.26 dB, respectively. It corresponds to perceptually high quality reconstructed image with minimum distortion with the use of fuzzy logical bit block in the proposed method. Fig. 3 shows the reconstructed images for the sample test image of cameraman. Visually, all the test images are reconstructed well, but the proposed method with fuzzy logical bit block is shown to be superior with slightly better PSNR values in comparison with using Canny logical bit block in the proposed method and the conventional BTC and ABTC methods. The raggedness and the jagged appearance are greatly reduced from the reconstructed images by the proposed method with fuzzy logical bit block. Also with the fuzzy logical bit block, the ringing artifacts at sharp edges are considerably minimized in the reconstructed image.

IV. CONCLUSIONS

The proposed compression method based on fuzzy edge image has shown to be superior to the conventional BTC and ABTC methods. Several test images have been coded with the proposed method, and the resulting reconstructed images are much better in terms of visual quality. The test results also demonstrate that the performance of the proposed method with the use of fuzzy logical bit block is better than the proposed method with Canny logical bit block and the conventional BTC and ABTC methods concerning the PSNR values. The RMSE values have been found to be lower for the proposed method with fuzzy logical bit block. Also with the fuzzy logical bit block, the method allows considerable reduction of the ringing effect, which usually occurs in the vicinity of sharp edges. This new technique is easier to implement in software, since the equations are less complex. The CFED algorithm used in the proposed method has been tested and evaluated with a set of classical edge detectors on the basis of the results of the Canny edge detector

TABLE III
PERFORMANCE OF THE PROPOSED METHOD

Image	CFED#		FEOBP@		Canny		CEOBP+	
	RMSE*	PSNR$	RMSE*	PSNR$	RMSE*	PSNR$	RMSE*	PSNR$
Cameraman	11.18	27.16	8.48	29.57	16.19	23.94	10.11	28.03
Lena	10.24	27.93	7.52	30.61	13.84	25.31	8.62	29.42
Peppers	12.03	26.52	7.78	30.32	14.56	24.87	8.49	29.55
Jet	13.96	25.23	9.65	28.44	17.37	23.34	10.26	27.91
Mandrill	18.24	22.91	15.10	24.55	28.12	19.15	18.30	22.88
Tank	11.42	26.98	7.62	30.49	13.47	25.54	8.75	29.29

: Competitive fuzzy edge detector, @ : Fuzzy edge ORed with bit plane (fuzzy logical bit block),
+ : Canny edge ORed with bit plane (Canny logical bit block), * : Root mean square error,
& : Mean absolute error, $: Peak signal to noise ratio

TABLE IV
PERFORMANCE OF ABTC AND CONVENTIONAL BTC METHODS

Image	ABTC								Conventional BTC	
	8 bit planes		16 bit planes		32 bit planes		64 bit planes			
	RMSE*	PSNR$	RMSE*	PSNR$	RMSE*	PSNR$	RMSE*	PSNR$	RMSE*	PSNR$
Cameraman	10.50	27.71	9.63	28.46	9.91	28.21	10.01	28.12	8.75	29.29
Lena	9.34	28.72	8.95	29.09	8.95	29.09	9.54	28.54	7.59	30.52
Peppers	11.11	27.22	10.39	27.80	10.58	27.64	10.52	27.69	7.83	30.26
Jet	12.44	26.23	11.18	27.15	11.19	27.15	11.65	26.81	9.89	28.22
Mandrill	22.20	21.20	19.73	22.22	20.13	22.05	21.16	21.62	15.21	24.29
Tank	9.80	28.31	9.77	28.33	9.88	28.23	10.28	27.89	8.12	29.87

* : Root mean square error, & : Mean absolute error, $: Peak signal to noise ratio

prior to applying for image compression. As future work, the bit rate of the proposed method can be improved further with quantization of the output levels to lesser number of bits.

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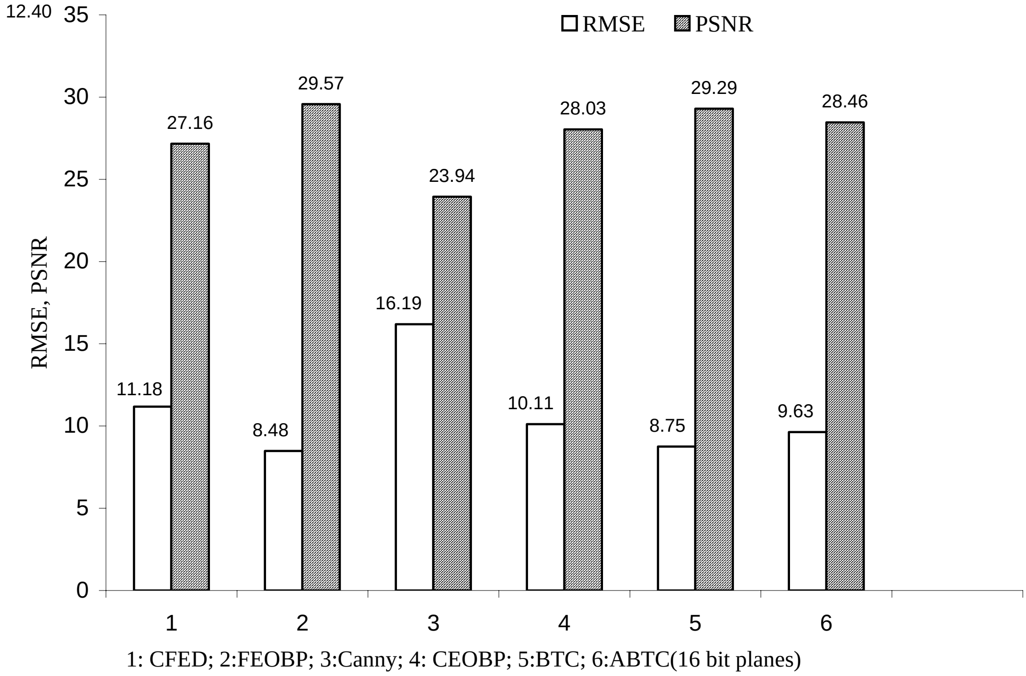

Fig. 2. RMSE and PSNR values of proposed, conventional BTC, and ABTC methods for Cameraman image.

Fig. 3 Reconstructed images of Cameraman by (a) proposed method with fuzzy logical bit block (b) conventional BTC (c) ABTC with 16 predefined bit planes.