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Original Article

A Novel Dual-Stage Compression Model Using RGC Bit-Planes and Refined Huffman Coding

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***Abstract** - The need for cost-effective image compression keeps increasing even after the availability of numerous advanced methods. Though diverse means have been put forward, the problem of drastically effective compression still stands. This work presents an influential lossless and lossy compression method for grayscale images with the help of the Reflected Grey Code (RGC) that is used together with a newly designed Refined Huffman (RH) coding scheme, dubbed as RGC+RH. The 8-bit pixel intensities are initially converted into RGC, followed by Bit-Plane Slicing (BPS), and then RH coding is performed on each bit plane. In the lossless mode, all eight coded planes are transmitted and employed for the reconstruction. In the lossy mode, only the chosen Most Significant Bit (MSB) planes are taken into account. The efficiency of the suggested method is tested against that of the standard Modified Huffman (MH) technique by using the same metrics: Compression Ratio (CR), Percentage Memory Saving (PMS), Bits Per Pixel (BPP), Peak Signal-to-Noise Ratio (PSNR), and Mean Square Error (MSE).*

***Keywords** - Bits Per Pixel (BPP), Bit-Plane Slicing (BPS), Peak Signal-to-Noise Ratio (PSNR), Refined Huffman (RH), Reflected Grey Code (RGC).*

1. Introduction

A competent solution to address problems related to transmission bandwidth, speed, and storage requirements is the Image Compression techniques, which are used very efficiently [1]. The representation of Digital images involves the introduction of redundancies in the data. The different redundancies visible are (i) Coding redundancy, (ii) interpixel redundancy, and (iii) Psychovisual redundancy [1]. Coding redundancy tries to minimize the number of bits that are used to represent the intensities of the pixels without a significant visual loss of the reconstructed multimedia data.

This research work is about the use of Variable Length Codewords rather than Fixed Length Codewords (FLC) for the reduction of coding redundancy. FLCs are not able to achieve compression because the length of code words is the same for all intensities [2], while in VLCs the lengths of the code words are determined based on the probabilities of the pixel intensities (source symbols) [3].

A fixed-length code does not imply that the total code size will be reduced when it is to be sent. For example, it is explained that some characters in the image data may occur more frequently than others; however, it still requires the same number of bits as the most frequently occurring character [2]. Hence, a prefix, free code for compression, can be an efficient way to solve the problem. The papers [4, 5] have discussed Variable, Length Codes (VLCs), and [6] has presented a hybrid compression algorithm; both [4, 5] have adopted Huffman code to reduce the total bit length for different applications. A modified Huffman encoding and decoding procedure technique is proposed in [7] and used to compress images, also supporting efficient lossless compression over wireless sensor networks [8]. Several researchers [9, 10] have implemented the MH coding technique for various applications such as mobile and security.

The RGC is one of the ways of representing the binary numeral system in which two consecutive values differ in only one bit. Gray codes find great applications in hardware, generating a normal sequence of binary numbers that can lead to error or ambiguity during the transition from one number to the next. Hence, the Gray code is capable of removing this problem without difficulty, as only one bit changes its value in any transition between two numbers [11].

Bit-plane slicing is one of the oldest and simplest compression methods adopted for Lossless compression. The gray-coded representation of image intensities can be encoded by decomposing into binary planes and then applying any coding technique to achieve compression [12, 13]. Bit-plane Decomposition with run-length coding or Huffman coding are the famous coding techniques employed for compression [14]. In this research work, the author has exploited the use of the Reflected Grey Code (RGC) coded image with Bit-plane decomposition. The individual decomposed binary bit-planes are encoded using the author's proposed Refined Huffman (RH) and compared with existing Modified Huffman (MH) coding [15].

2. Review of Literature

Image compression has become increasingly vital with the rapid growth of digital imaging technologies and the widespread use of bandwidth-limited communication networks. Efficient compression mechanisms enable the reduction of redundant information while preserving the essential structure and quality of the image. One of the main reasons why lossless methods like Huffman coding are still very much relevant in present-day compression pipelines is their straightforwardness, trustworthiness, and almost zero information loss, as pointed out in [16].

Most traditional and new methods substantially rely on the creation of encoding tables, especially of Huffman-based schemes, for the optimal representation of symbol frequencies [17]. Besides that, the necessity of compression is made very clear in telemedicine, where, to facilitate fast and accurate transmission of high-resolution diagnostic images, compression plays a vital role in the efficiency of clinical workflows [18].

2.1. Classical and Refined Huffman Coding Approaches

Huffman coding, as in the seminal work of Huffman [19], is the main reference and has been mostly used in digital pictures because of its optimal prefix code property and the simplicity of its implementation. However, the conventional Huffman coding has difficulties when distributions of symbols are highly variable or in the case of image datasets that have non-uniform statistical characteristics. The performance of static Huffman coding in such cases may be low, as stated in the research [20]. The improvements of the classical algorithm have been concentrated on adaptive table construction, statistical refinement, and the integration with other compression models.

The adaptation of Huffman coding changes the frequencies of symbols during the encoding process and thus can give better results in situations where the symbols' probabilities change either in space or time [21]. Furthermore, context-based Huffman coding utilizes the spatial correlations of pixels to get more accurate probability estimations, which, in turn, result in higher compression ratios for complex images [21, 22]. These improvements demonstrate how Huffman coding is still relevant, as the researchers keep on modifying and extending its features.

2.2. Hybrid and Transform-Based Compression Methods

Hybrid schemes that combine Huffman coding with transform-domain methods have shown impressive advances in compression effectiveness and image quality. In [23], the fusion of 2D Discrete Wavelet Transform (2D DWT), Principal Component Analysis (PCA), and canonical Huffman encoding reached higher compression ratios by focusing signal energy in a very small number of coefficients. Besides, wavelet-based techniques are also used widely in medical imaging to provide a versatile multi-resolution representation and allow lossless Region of Interest (ROI) coding, as evidenced in [24].

One of the most common integrations of dictionary-based algorithms like LZ77 with Huffman coding is to combine them for better performance of lossless image compression. Their combined operation provides the dictionary stage with the means to remove repeated patterns, and then Huffman coding is used to compress encoded symbols optimally [25]. Research on VLSI layout image processing has been pointing to the same requirement of efficient entropy coding methods. Dai and Zakhor have shown that combinatorial codes, although of lower complexity, can be on a par with arithmetic and Huffman coding in compression efficiency [21, 22].

2.3. Alternative Coding Architectures and Probability Modeling

Recent developments in image compression have been highlighted through parallel Entropy, coding architectures, and enhanced statistical models. In particular, probability modeling has a major effect on the coding efficiency in systems that operate at high throughput. The paper [26] presents the probability models specifically for parallel processing units of image data and shows the improvements achieved in coding accuracy as well as overall system efficiency. Psychovisual bit allocation based on Tchebichef, as in [27], is just another example of the future where perceptual thresholds are used to distribute bits in order to lower the average Huffman code length and, at the same time, keep the visual quality of the image intact. Besides that, architectures for compressing data that are energy-efficient and have low memory requirements have been the focus of the research to a great extent, especially in the case of IoT and embedded multimedia devices. The techniques introduced in [28] are aimed at lessening the complexity of the hardware while still keeping the performance of the compression at a satisfactory level. There are also systems that take advantage of optimization methods like Particle Swarm Optimization (PSO) that can enhance embedding and compression performance if combined with Huffman encoding [29]. More work has been done on the development of error-resilient variable-length codes whose main purpose is to limit the error propagation during the transmission of images and thus, increase the stability of entropy-coded bit streams [30].

2.4. Reflected Gray Code (RGC) for Image Compression

Reflected Grey Code (RGC), which is a code where only one bit changes between successive values, has been used in a number of digital systems to reduce the occurrence of transition errors. The main reason for its application to image compression is the ability to generate more normal distributions when the pixel values are represented. some authors show that the memory usage can be greatly reduced if the binary differences in the dithered images are grouped, because this way the repetitive patterns can be encoded in a much simpler way. Before entropy coding, the redundancy that exists in the data can be removed if the pixel intensity values are converted into RGC, which is a very promising method that can be used as a preprocessing step or a final step in Huffman coding.

2.5. Contemporary Encoding Systems and Applications

Recent patents and industrial methods reveal that the research on entropy coding innovations is not yet complete. For instance, Takada and Matsuzaki [31] illustrate an image encoding device that automatically changes the Huffman tables by analyzing the characteristics of the compressed JPEG encoded data. On the other hand, navigation database compression techniques speak about the use of specialized Huffman-based methods to achieve the compression of geospatial datasets [29]. At the same time, value-based data compression patents are delving into the issue of defining the importance of the symbols while also taking into account their redundancy [32]. Advanced image compression systems are often multi-stage pipelines that combine transform-based and entropy-based methods. Tian et al. [31] have come up with an adaptive compression method that involves wavelets, fractal iteration, and Huffman encoding. The method they proposed performed better than the previously existing ones. The work reported in [30] regarding error-resilient synchronization codewords for Variable Code Length (VLC) is an example of how the authors emphasize the problem of sustaining communication that is still reliable in the presence of noise, which is the main issue in the image transmission area.

2.6. Positioning of the Proposed Method

One of the main points that can be found in almost all of the papers is that improvements should be achieved by combining different techniques, making probability more accurate, and reducing redundancy. The three of them, namely Reflected Gray Code (RGC) and refined Huffman coding, are very close to these research directions. RGC conversion is more general than the others because it reduces redundancy at the level of symbol representation, while refined Huffman variants improve entropy coding efficiency. The synergy of these techniques shows strong potential for enhanced lossless image compression, providing a novel contribution to the ongoing evolution of modern compression strategies.

3. Related Work

The researcher in [14] proposed a classifier using Median Filtering Detection (MFD) for forged images. Bit-plane slicing of the forged image is carried out first, then feature vectors are extracted using an autoregressive model. Bit planes 1, 2, and 8 are used for testing purposes. The extracted features are used for training a Support Vector Machine (SVM) classifier. The results were compared with other filtering techniques, such as the Gaussian and averaging filters, for a window size of 32X32 and 64X64. Experiments were further carried out by up-sampling and down-sampling of the test images. The performance is measured in terms of Area under the curve, and achieved better results.

In [33], the researcher proposed a variation to Run Length Coding named I3BN. Initially, the grey-scale image is sliced into bit planes, and then I3BN is applied to each plane. In this algorithm, instead of transmitting the intensity value of a pixel and its run length as in conventional RLE, they are transmitted in a particular data structure. The proposed data structure could reduce the number of bits used for the representation of run lengths and also achieve compression almost twice for some images. The results were compared with the classical RLE algorithm.

In [34], the researcher proposed restoration of digital images using the threshold histogram method. The images were bit-plane sliced, stored, and a restoration procedure was applied. The restoration method used a diagonal scan order, left-to-right and up-to-down. Based on the average gradient of the image vector, the direction of the pixels to be processed can be reconstructed, and the damaged images can be reconstructed. The reconstruction time was reduced to 10 seconds.

In [35], the researcher has proposed a simple lossless compression scheme in which the grey-scale image has been sliced into bit planes. Predictive coding is applied on individual planes, and seed values, coefficients, and residual values were collected. Run Length Coding was applied, and achieved good compression.

In [36], the author has proposed a Reversible Data Hiding in Encrypted Images (RDHEI) compression method. The method involved four stages of processing: 1. Vacation room, 2. Encryption 3. Embedding the data 4. Extraction & recovery of the image. The vacation room consisted of two procedures: pixel prediction followed by bit-plane arrangement and compression. In the second step, a matrix of pseudo-random values is generated, which is used for hiding, and the matrix is embedded into the pixels. The last stage of processing involved the extraction of the hidden matrix and recovered the original image. The parameters PSNR, SSIM, and embedding rate were calculated, and achieved the best results.

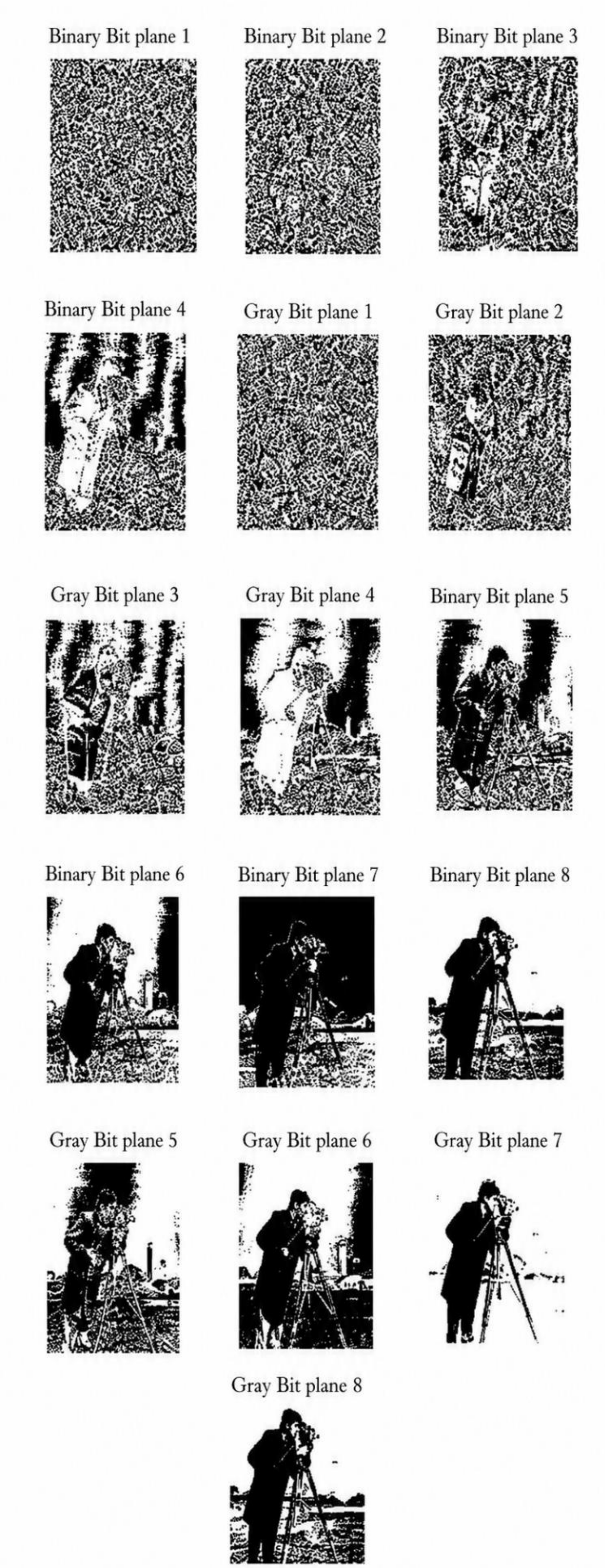

Fig. 1 Binary and Grey planes of the image cameraman

4. Proposed Methodology

Mostly, 8-bit grey-scale images are used in general for storage and transmission purposes. In order to develop an efficient Lossless/ Lossy compression system for grey-scale images, the author has proposed the use of grey-coded binary-plane decomposition applying RLE and then Huffman coding. For RLE to be effective, long runs of very similar grey values would result in very good compression rates for the code.

To improve the compression, encode the grey values with their binary Gray codes. A Gray code is an ordering of all binary strings of a given length so there is only one bit change between a string and the next. Consider an 8-bit image and its binary representation decomposed into binary planes, and the Reflected Gray Code (RGC) representation of the decomposed planes is shown in Figure 1.

The decomposed bit planes are shown in the figure. It can be observed that bit planes for RGC coded are highly correlated and lead to higher effective compression ratios when RLE is applied. Most of the information is available in MSB planes, i.e., 4, 5, 6, 7, and 8, and if LSB planes 0,1,2,3 are neglected, also much of the information may not be lost. Based on the applications where we use the compression technique, we use either all planes (Lossless) or a few planes (Lossy).

To improve the compression ratio further, the author has used MH to encode the run lengths after RLE. The MH compression technique has a dictionary of Variable Length Code words to encode the run lengths [15]. The MH dictionary consists of separate code words for white and black run lengths.

Based on the probabilities of run lengths, the codewords of varied length are assigned using Huffman coding. Encoding the run lengths using these codewords will reduce the number of bits, as these codewords are variable lengths. The Block diagram implementation of the existing MH compression-based model is shown in Figure 2.

The proposed RH coding technique uses an RH dictionary, which the author has proposed [15]. This dictionary has a reduced average length of code words compared to the MH dictionary. The code words are assigned based on the probabilities of run lengths. Most probable run lengths were assigned shorter lengths of code words, and least probable run lengths were assigned with longer lengths of code words [15].

The author has exploited the advantage of RGC, and the author proposed the RH compression model, which is shown in the figure. In the proposed block diagram implementation, it can be observed that the use of the RH dictionary instead of the MH dictionary is employed.

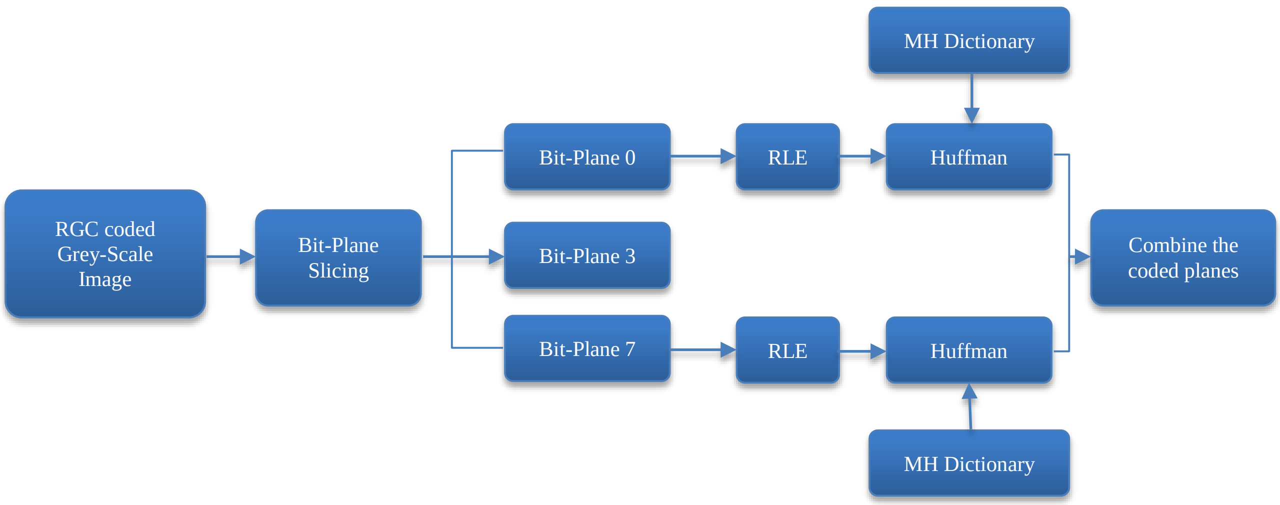

Fig. 2 Transmitting block diagram

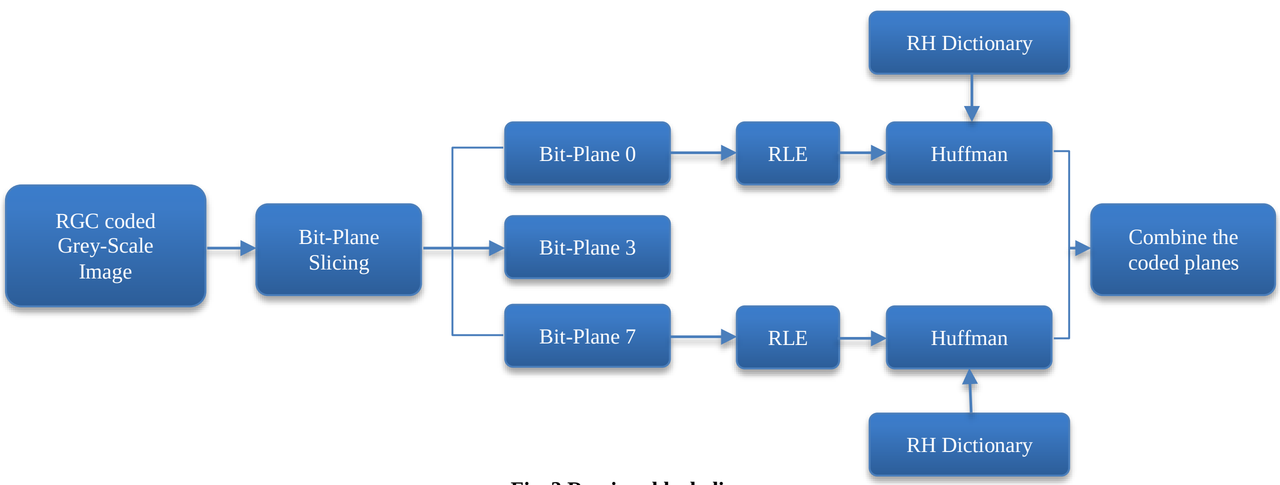

Fig. 3 Receiver block diagram

The implementation procedures for encoding and decoding at the transmitting and receiving ends are explained in the algorithms below.

4.1. Transmitter Section

At the transmitter side, the operation starts with an 8-bit grey-scale image. Pixel values are encoded using the Reflected Gray Code (RGC) to make the coding more efficient. The image is then bit-plane sliced, which breaks it down into eight separate binary planes. In the case of lossless compression, all the eight bit-planes are sent, while in the lossy mode, only the higher-order significant planes are transmitted, and the Lower Least Significant Bit (LSB) planes are discarded to achieve compression.

Each bit-plane is additionally transformed with the Refined Huffman (RH) compression method, where Run-Length Encoding (RLE) is performed on the sequences of black and white pixels and the obtained run lengths are encoded using the RH dictionary of optimized code words. At last, the compressed bit-planes are concatenated and transmitted as the output of the transmitter section.

4.2. Receiver Section

On the receiver side, the operation begins with the arrival of the encoded file, changing its size to the dimensions of the original image. The reconstructed image is then separated into Bit-Planes, where all eight planes are taken for the lossless reconstruction, while only the higher-order planes, either planes 4 to 8 or planes 5 to 8, are used for the lossy reconstruction. Each plane is opened by getting the run lengths that match the encoded code words through the Refined Huffman (RH) dictionary. After the decoding, the bit-planes are merged to get the reconstructed image. To measure the system's efficiency, Compression Ratio (CR) and Bits Per Pixel (BPP) are figured out for the lossless mode, while Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) are calculated for the lossy mode. The results obtained here serve for a comparative study with those derived from binary-coded images by using the Modified Huffman (MH) coding technique.

5. Findings and Analysis

This section describes the results and discussions of the experiments conducted to evaluate the performance of the proposed RH-based compression technique with the existing MH-based compression technique. The proposed and existing techniques are modeled in MATLAB 2024a. Microsoft Windows 11 operating system, 64-bit Intel i7-class Pentium processor with 16 GBPS RAM, and a Graphics Processing Unit are used for carrying out the experiment study. Performance is evaluated in terms of Percentage of Memory Saving (PMS), Compression Ratio (CR), Number of Bits Per Pixel (BPP), and Peak Signal to Noise Ratio (PSNR). Experiment results are presented as two cases: (1) Lossless and (2) Lossy. For experimental analysis, 8-bit grey scale images are considered [21]. At the receiving end, assuming a noiseless environment, reconstruction of images is carried out, which is presented at the end of this section. The parameters MSE and PSNR are evaluated to analyze the performance of the proposed RH compression technique.

5.1. Lossless Compression

In Lossless compression, after encoding the individual bit-planes, all the bit-planes were transmitted, and at the receiving end, all eight planes were used to reconstruct the image. The results are presented for binary coded and RGC with existing MH and proposed RH. The performance of CR is presented in Table 1 below.

Table 1. Comparison of CR for lossless binary and Grey coded images using MH and RH

S.No.	Image Name (Tif)	Binary coded Image compressed using existing MH	RGC coded Image compressed using existing MH	RGC coded Image compressed using proposed RH	% Improvement in CR
1	Mat	1.3398	1.6957	1.8455	8.834
2	F18_200	1.8259	2.2526	2.4639	9.380
3	F19_400	0.9694	1.1558	1.2623	9.214
4	F20_400	1.4978	2.0495	2.1404	4.435
5	Target	1.6651	1.8655	2.0661	10.753
6	Seismic	1.8740	3.1542	3.1548	0.019
7	Txtur	1.2084	1.2935	1.3181	1.902
8	Txtur2	1.2293	1.4178	1.4553	2.645
9	Cameraman	2.0304	2.2237	2.3218	4.412
10	Pirate	1.3944	1.4529	1.5511	6.759
11	Living room	1.3317	1.3737	1.4713	7.105

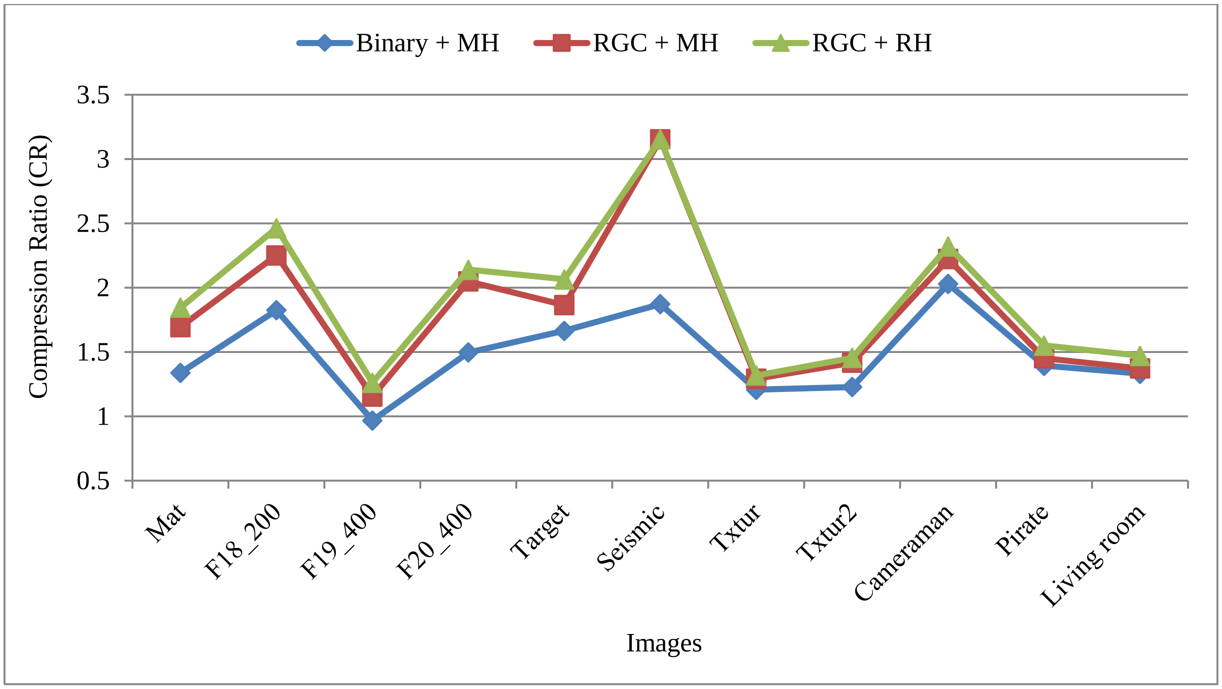

Fig. 4 Comparison of CR for lossless binary and Grey coded images using MH and RH

It can be observed that the CR's obtained by the Gray coded representation of images are higher than the binary representation of the images for both the existing MH and proposed RH techniques. The CR's obtained by the proposed RH are higher than the CR's obtained by the existing MH technique. A maximum percentage improvement of 10.753% to a minimum of 0.019% is obtained for images 5 and 6, respectively.

The line graph corresponding to Table 1 illustrates the variation of compression ratio for different test images under lossless compression. It is evident that RGC-coded images consistently achieve higher CR values compared to binary-coded images when compressed using the existing MH technique, indicating the advantage of Gray code representation in reducing redundancy.

Besides, the RGC+RH method that has been suggested is better than both Binary+MH and RGC+MH for almost all the pictures, which indicates that the coding efficiency has been enhanced because of the refined Huffman dictionary. The difference in performance is quite significant for images like Target and F18_200, whereas only a slight improvement can be seen for the Seismic image, which is a reflection of image-dependent statistical characteristics. Overall, the trend confirms the superiority of the proposed RH coding in enhancing lossless compression performance.

The performance of the parameter PMS is shown in Table 2. It can be seen that the PMS values are higher for the gray-coded representation of images than the binary-coded representation for both MH and RH coding.

Table 2. Comparison of PMS for lossless binary and Grey coded images using MH and RH

S.No.	Image Name (Tif)	Binary coded Image compressed using existing MH	RGC coded Image compressed using existing MH	RGC coded Image compressed using proposed RH	% Improvement by RH over MH
1	Mat	25.359	41.027	45.814	11.667
2	F18_200	45.233	55.607	59.414	6.846
3	F19_400	3.159	13.480	20.780	54.153
4	F20_400	33.234	51.208	53.280	4.047
5	Target	39.944	46.395	51.600	11.218
6	Seismic	46.639	68.296	68.302	0.009
7	Txtur	17.245	22.690	24.133	6.359
8	Txtur2	18.653	29.468	31.286	6.168
9	Cameraman	50.749	55.030	56.930	3.453
10	Pirate	28.287	31.172	35.530	13.979
11	Livingroom	24.908	27.204	32.033	17.751

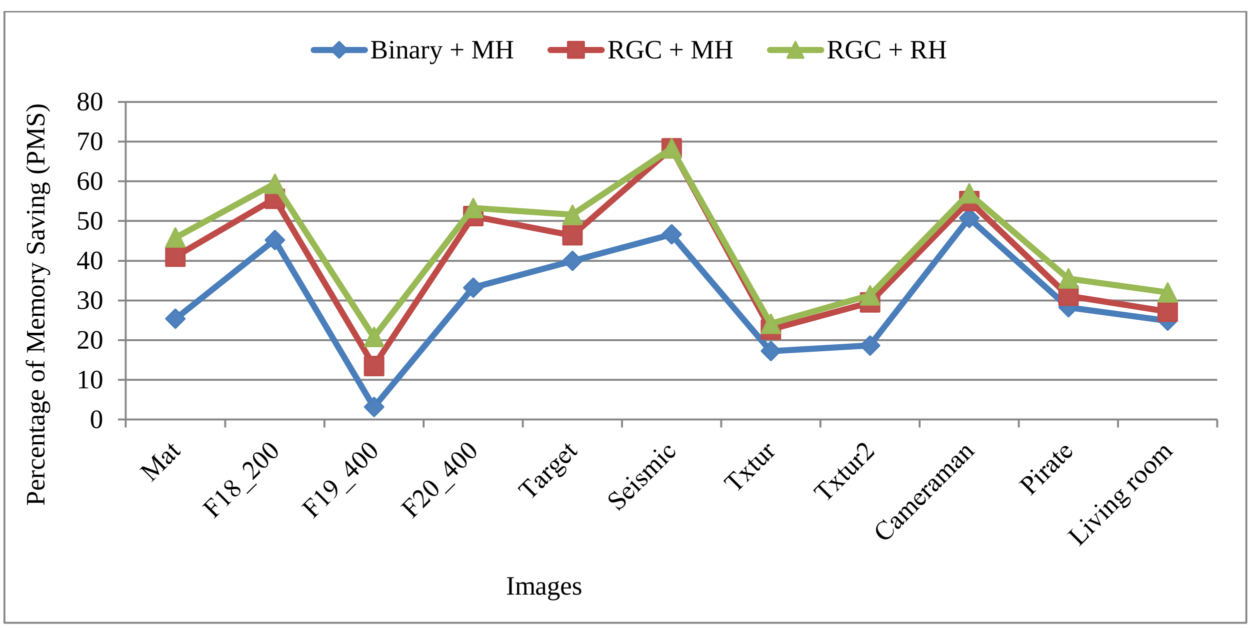

Fig. 5 Comparison of PMS for lossless binary and Grey coded images using MH and RH.

The PMS values obtained by the proposed RH are higher than the existing MH. A maximum saving of 54.15% and a minimum of 0.009% is achieved for Image 3 and Image 6, respectively.

The line graph of Table 2 presents the percentage of memory savings achieved by different coding schemes. The results clearly show that RGC-based representations provide higher memory savings than binary representations for both MH and RH techniques. Among all methods, the proposed RGC+RH consistently yields the maximum PMS values for nearly all images, indicating more effective utilization of storage resources. Significant improvement is observed for images such as F19_400 and Livingroom, whereas minimal improvement is seen for the Seismic image, which aligns with its uniform texture characteristics. These observations validate that the refined Huffman coding, combined with RGC representation, substantially enhances memory efficiency in lossless compression.

For an 8-bit grey scale image, the number of bits used to represent a pixel is 8. In the based compression technique, variable-length code words are used to represent the pixels, so fewer than 8 bits will be required. The parameter Bits Per Pixel (BPP), which represents the number of bits used to represent a pixel on average for the image, is computed for both the existing MH and the proposed RH coding techniques. The results are presented in Table 3.

Table 3. Comparison of BPP for Lossless Binary and Grey coded images using MH and RGC+RH

S.No.	Image Name (Tif)	Binary coded representation (BPP)	Binary coded Image compressed using existing MH	RGC coded Image compressed using existing MH	RGC coded Image compressed using proposed RH	% reduction in BPP by RH over MH
1	Mat	8	5.9713	4.7177	4.3348	8.116
2	F18_200	8	4.3814	3.5515	3.2468	8.579
3	F19_400	8	8.2527	6.9219	6.3378	8.438
4	F20_400	8	5.3412	3.9034	3.7376	4.248
5	Target	8	4.8045	4.2884	3.8721	9.708
6	Seismic	8	4.2689	2.5363	2.5358	0.020
7	Txtur	8	6.6204	6.1849	6.0696	1.864
8	Txtur2	8	6.5078	5.6424	5.4973	2.572
9	Cameraman	8	3.9401	3.5976	3.4456	4.225
10	Pirate	8	5.7371	5.5063	5.1575	6.335
11	Livingroom	8	6.0074	5.8237	5.4372	6.637

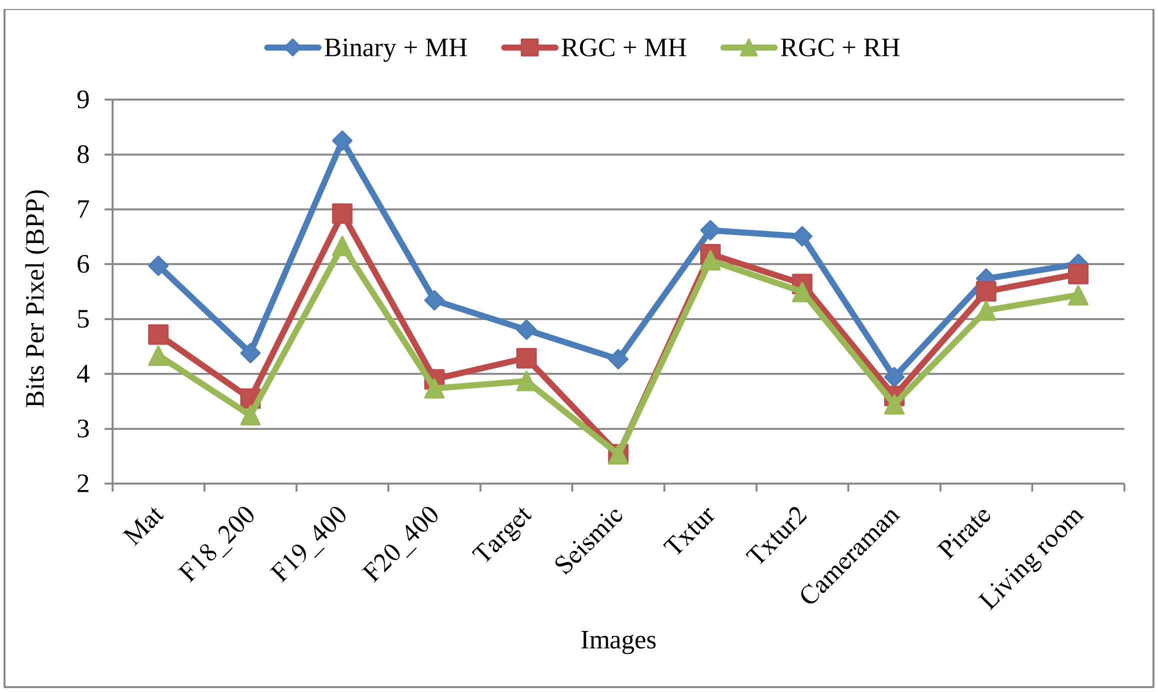

Fig. 6 Comparison of BPP for lossless binary and Grey coded images using MH and RGC+RH.

It can be observed that the BPP values are reduced for the proposed RH in comparison with the existing MH. A maximum % saving of BPP on an average obtained by RH is 9.708, and a minimum of 0.020% in comparison with the existing MH.

The line graph derived from Table 3 compares the average number of bits required to represent a pixel for different compression schemes. It can be observed that Binary+MH results in the highest BPP values, while RGC-based approaches significantly reduce the bit requirement.

The proposed RGC+RH method achieves the lowest BPP across most test images, confirming its ability to encode image information more compactly. Maximum reduction in BPP is observed for images such as Target and F18_200, whereas a negligible reduction is noticed for the Seismic image due to its inherent structural properties. The overall downward trend of the RGC+RH curve demonstrates the effectiveness of the proposed approach in minimizing bit consumption without information loss.

5.2. Lossy Compression

In a lossy compression method, the entire original data will not be transmitted. Instead, some loss of data is allowed, which [1] helps in achieving a higher Compression Ratio (CR) than the Lossless method. In the Bit-Plane slicing method, instead of transmitting all the bit-planes, only a few important Most Significant Bit (MSB) planes can be transmitted.

Some of the Least Significant Bit (LSB) planes can be neglected in transmission, which helps in achieving compression. In this case study, some of the LSB planes are neglected, and a few MSB planes are encoded using the proposed RH, and the results are compared with existing MH encoding. At the receiving end, the image is reconstructed using MSB planes after decoding. The parameters CR, PSNR, and MSE are used for analysis purposes.

The results of CR are tabulated in Table 4. A comparison between Lossless and Lossy using the proposed RH and MH is shown. It can be observed that the CR's obtained for Lossy are higher than those for Lossless. Experiments were conducted by considering planes 4 to 8 and planes 5 to 8 for Lossy compression. These planes are encoded using the proposed RH compression technique and compared with the MH technique.

Table 4. Comparison of CR for Lossy Binary and Grey coded images using MH and RGC+RH

S.No.	Image Name (Tif)	Binary coded using MH (Lossless)	RGC coded using MH (Lossless)	RGC coded using proposed RH (Lossless)	RGC coded planes using 4,5,6,7,8 & Proposed RH (Lossy)	RGC coded using planes 5,6,7,8 & Proposed RH (Lossy)
1	Mat	1.3398	1.6957	1.8455	5.6248	9.2011
2	F18_200	1.8259	2.2526	2.4639	8.1241	13.0289
3	F19_400	0.9694	1.1558	1.2623	3.2560	5.1401
4	F20_400	1.4978	2.0495	2.1404	7.5504	12.9077
5	Target	1.6651	1.8655	2.0661	4.2239	5.9110
6	Seismic	1.8740	3.1542	3.1548	14.0508	25.2210
7	Txtur	1.2084	1.2935	1.3181	1.8740	2.8131
8	Txtur2	1.2293	1.4178	1.4553	3.0198	4.9354
9	Cameraman	2.0304	2.2237	2.3218	7.6735	12.5086
10	Pirate	1.3944	1.4529	1.5511	5.0223	8.2794
11	Livingroom	1.3317	1.3737	1.4713	4.7307	7.8665

From the tabulated results, it can be observed that CR's obtained for Lossy are higher than the CR's achieved for Lossless (8-pixel transmitted). Further, the CR is improved by encoding the planes using RH for Planes 5 to 8 in comparison with encoding Planes 4 to 8. A maximum CR of 14.0508% to a minimum of 3.0198 %is achieved for image 6 and image 3 by considering planes 4 to 8. Similarly, a maximum CR of 25.2210% and a minimum CR of 4.9354 % is achieved for images 6 and 8 by considering Planes 5 to 8.

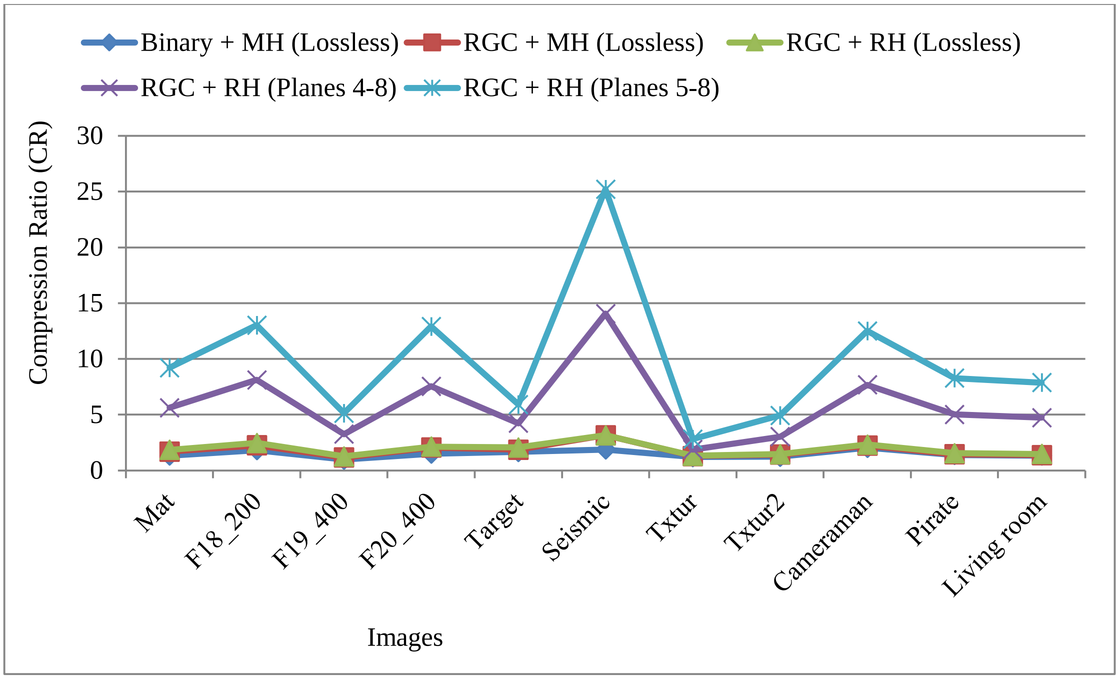

Fig. 7 Comparison of CR for Lossy Binary and Grey coded images using MH and RGC+RH.

The line graph for Table 4 compares compression ratios obtained under both lossless and lossy conditions. It is evident that lossy compression significantly outperforms lossless compression in terms of CR for all images. RGC+RH with planes 5 to 8 is the lossy configuration that results in the highest CR, with planes 4 to 8 coming as a close second, thus indicating the effect of removing the lower significant bit planes. The Seismic picture is the one to have the highest CR, which means that there is a lot of redundancy in its MSB planes. On the other hand, lossless techniques have noticeably lower CR figures, even when RGC and RH are used. These results clearly demonstrate that selective MSB-based lossy compression using the proposed RGC+RH approach provides substantial gains in compression efficiency while maintaining acceptable reconstruction quality.

5.3. Reconstruction of Images

Further experiments are conducted to analyze the performance of reconstructed images using different planes. The parameters Mean Squared Error (MSE) and Peak-Signal-To-Noise Ratio (PSNR) are evaluated for both MH and RH coding techniques. It can be observed that the reflected gray code representation of the image has given the best results for MSE and PSNR in comparison with Binary-coded planes. For Lossless, as all the planes are transmitted, the MSE will be zero, and we will not discuss the PSNR. For the lossy case, the reconstruction of the image is carried out by considering planes 4 to 8 and planes 5 to 8.

5.3.1. Reconstruction using Planes 5 to 8

In this, Planes 5 to 8 are used for the reconstruction of the image. The parameters MSE and PSNR are used to analyze the performance of the proposed (RGC+RH) above the existing MH Technique. The MSE is reduced drastically for the Gray-coded representation of the image coded using the proposed RH, as can be observed in Table 5. A maximum reduction of 92.90% to a minimum reduction of 82.67% is achieved by the proposed (RGC+RH) coding method over the MH compression method. In terms of PSNR, the proposed (RGC+RH) could reconstruct images with improved values compared with the existing MH coding. A maximum improvement in PSNR of 44.54 dB to a minimum of 26.23 dB is attained by the proposed (RGC+RH) method.

Table 5. Comparison of MSE & PSNR for lossy binary and Grey coded images using MH and RGC+RH considering plane 5 to plane 8

S.No	Image Name (Tif)	MSE			PSNR in dB		
		Binary coded Using existing MH	Gray coded Using the proposed RH	% Reduction in MSE	Binary coded Using MH	Gray coded Using RH	% Improvement in PSNR
1	Mat	77.1726	9.8436	87.24	29.2562	38.1993	30.57
2	F18_200	88.4507	6.2791	92.90	27.7785	40.1518	44.54
3	F19_400	68.6474	10.721	84.38	29.7646	37.8284	27.09

4	F20_400	69.436	9.1402	86.84	29.715	38.5212	29.64
5	Target	62.3157	5.026	91.93	30.1848	41.1186	36.22
6	Seismic	78.0049	8.3944	89.24	29.2096	38.8909	33.14
7	Txtur	73.9001	10.9967	85.12	29.4944	37.7182	27.88
8	Txtur2	76.8669	10.0439	86.93	29.2734	38.1118	30.19
9	Cameraman	81.4426	14.1155	82.67	29.0223	36.6338	26.23
10	Pirate.	78.8052	12.7399	83.83	29.1653	37.0792	27.13
11	Livingroom	77.3872	11.1283	85.62	29.2441	37.665	28.80

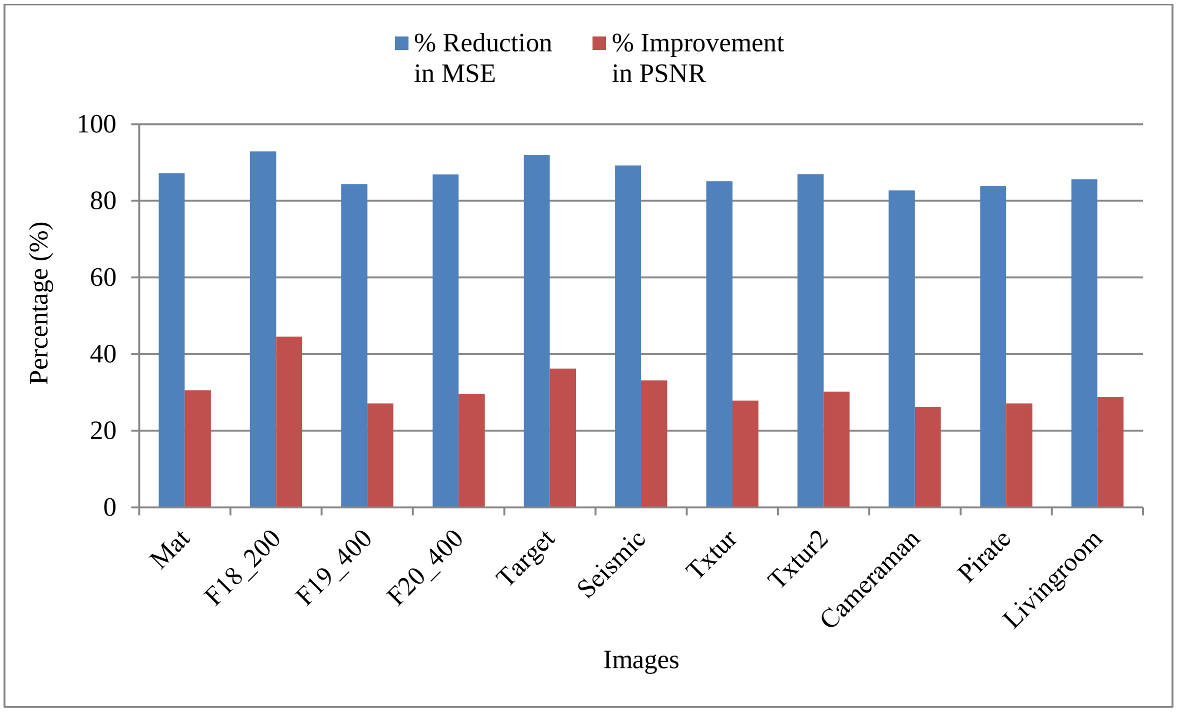

Fig. 8 Comparison of MSE & PSNR for lossy binary and Grey coded images using MH and RGC+RH considering plane 5 to plane 8

The bar chart derived from Table 5 illustrates the percentage reduction in Mean Squared Error (MSE) and the percentage improvement in Peak Signal-to-Noise Ratio (PSNR) achieved by the proposed RGC+RH method when compared to the existing MH technique for lossy reconstruction using planes 5 to 8. Basically, the proposed method has been able to bring down the MSE by a very large margin for all of the test images to a great extent; the reductions vary from about 82% to 93%, hence the reconstruction accuracy has been elevated to a very significant level. The same goes for PSNR improvements, which are in all cases very close to the 30% mark and, for the F18_200 image, the maximum value of 44.54% is attained.

These results confirm that the reflected Gray code representation combined with refined Huffman coding effectively preserves image quality while enabling aggressive compression. The consistent trend across diverse image types demonstrates the robustness and superiority of the proposed method in lossy image reconstruction.

5.3.2. Reconstruction using Planes 4 to 8

In this, Planes 4 to 8 are used for the reconstruction of the image. As one more plane, 4 is transmitted along with planes 5 to 8. In the reconstruction stage, the image will be reconstructed with reduced MSE and PSNR values for the proposed (RGC+RH) method.

The MSE is reduced drastically for the Gray coded representation of the image coded using the proposed (RGC+RH) and one extra plane 4, as can be observed in Table 6.

A maximum reduction of 90.82% to a minimum reduction of 80.53% is achieved by the proposed (RGC+RH) coding method over the MH compression method. In terms of PSNR, the proposed (RGC+RH) could reconstruct images with improved values compared with the existing MH coding. A maximum improvement in PSNR of 30.38 dB to a minimum of 20.07 dB is attained by the proposed (RGC+RH) method.

Table 6. Comparison of MSE & PSNR for lossy binary and Grey coded images using MH and RGC+RH, considering plane 4 to plane 8

S.No	Image Name (Tif)	MSE			PSNR in dB		
		Binary coded Using existing MH	Gray coded Using the proposed RH	% Reduction in MSE	Binary coded Using MH	Gray coded Using RH	% Improvement in PSNR
1	Mat	17.5376	2.7443	84.35	35.69	43.7465	22.57
2	F18_200	25.06	2.3012	90.82	34.14	44.5113	30.38
3	F19_400	16.7764	2.954	82.39	35.88	43.4267	21.02
4	F20_400	17.5372	3.302	81.17	35.69	42.9431	20.32
5	Target	14.6786	1.8417	87.45	36.46	45.4785	24.72
6	Seismic	17.504	2.7088	84.52	35.69	43.8031	22.70
7	Txtur	18.7599	3.6534	80.53	35.39	42.5038	20.07
8	Txtur2	17.5555	2.805	84.02	35.68	43.6584	22.34
9	Cameraman	17.4179	2.557	85.32	35.72	44.0535	23.33
10	Pirate	17.7814	2.864	83.89	35.702	43.5611	22.01
11	Livingroom	17.4937	2.7662	84.19	35.702	43.712	22.40

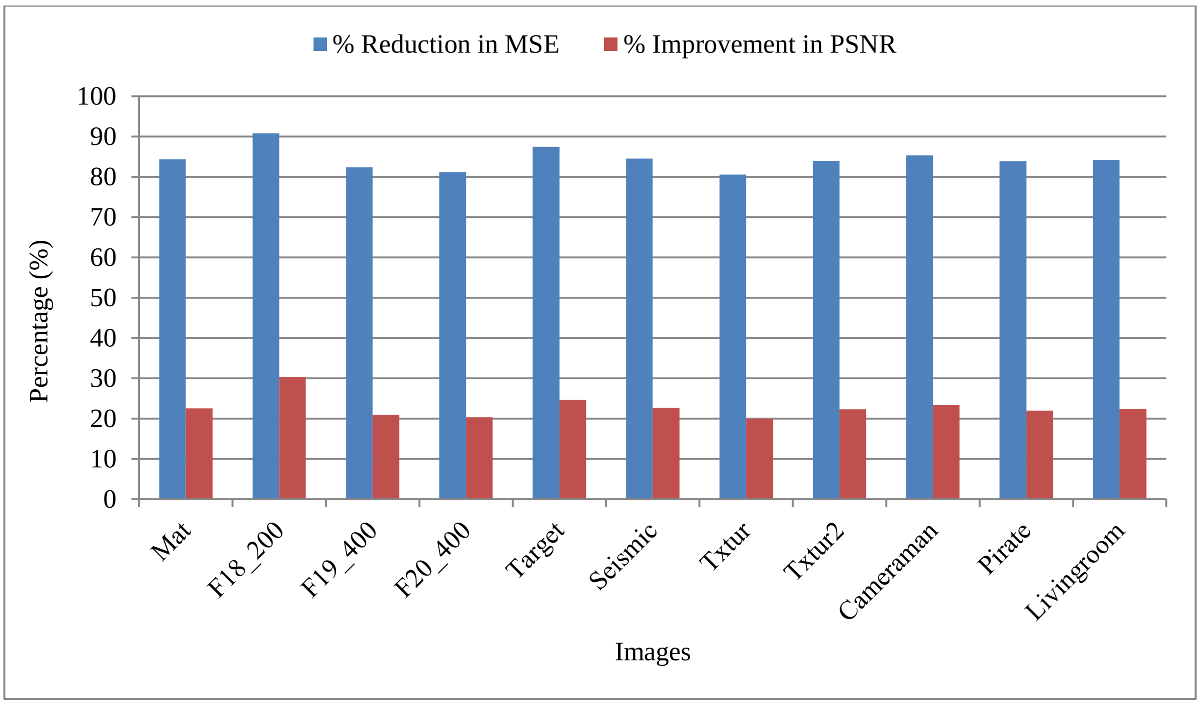

Fig. 9 Comparison of MSE & PSNR for lossy binary and Grey coded images using MH and RGC+RH considering plane 4 to plane 8

The bar chart corresponding to Table 6 illustrates the percentage reduction in Mean Squared Error (MSE) and the percentage improvement in Peak Signal-to-Noise Ratio (PSNR) achieved by the proposed RGC+RH method over the existing MH technique when lossy reconstruction is performed using planes 4 to 8. The results reflect a steady and statistically significant reduction in MSE that varies between about 80% and 91%, which is a clear indication that the reconstruction accuracy has been improved by the additional bit, plane. Moreover, PSNR enhancements are recorded in each photograph, their extent differing from 20% to 30%, thus indicating a better visual quality of the reconstructed images. The addition of plane 4 as compared to the use of planes 5 to 8 results in lower compression but higher reconstruction quality, thus pointing to the balancing of compression efficiency versus image fidelity. To sum up, the RGC+RH method put forward is capable of strong performance and high-quality reconstruction of the images of various types.

6. Conclusion

The paper presents an effective lossless and lossy compression method for grayscale images. The compression method presented is called (RGC+RH), which is a combination of reflected gray code and Refined Huffman code. Experiments were carried out for both lossless and lossy methods by dividing the gray image into bits and planes. In the case of lossless, all planes are used for encoding and reconstruction, while in the case of lossy, planes 5 to 8 and planes 4 to 8 are considered. The results obtained are compared with the well-known Modified Huffman (MH) coding technique. The RGC+RH method proposed yields an average gain of 5.95% in CR, 12.33% in PMS, and 5.522% in BPP for lossless compression over MH. In the case of lossy compression, an average CR increment of 5.95% and 9.8% is reported at different bit-plane selections. Also, the quality of reconstruction rises considerably, providing PSNR increases of 31.03% and 22.89% for varied planes versus MH. Moreover, the proposed method decreases MSE during reconstruction.

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