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Article

Reversible Data Hiding with Contrast Enhancement Using Bi-histogram Shifting and Image Adjustment for Color Images

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Abstract: Prior versions of reversible data hiding with contrast enhancement (RDHCE) algorithms strongly focused on enhancing the contrast of grayscale images. However, RDHCE has recently witnessed a rise in contrast enhancement algorithms concentrating on color images. This paper implies a method for color images that uses the RGB (red, green, and blue) color model and is based on bi-histogram shifting and image adjustment. Bi-histogram shifting is used to embed data and image adjustment to achieve contrast enhancement by adjusting the images resulting from each channel of the color images before combining them to generate the final enhanced image. Images are first divided into three channels—R, G, and B—and the Max, Med, and Min channels are then determined from these. Before histogram shifting, some calculations are done to determine how many iterations there will be for each channel. The images are adjusted to improve visual quality in the enhanced images after data has been embedded in each channel. The experimental results show that the enhanced images produced by the proposed method are qualitatively and aesthetically superior to those produced by some earlier methods, and their quality was assessed using PSNR, SSIM, RCE, RMBE, and CIEDE2000. The embedding rate obtained by the suggested method is acceptable.

Keywords: Contrast enhancement; bi-histogram shifting; image adjustment

1 Introduction

With the current advancement in multimedia, conventional artwork and printed works are converted into digital images. Images are frequently distorted as a result of the acquisition, processing, transmission, and storage processes, which lowers the overall clarity and quality of the images. In recent years, several contrast enhancement (CE) methods have been proposed in [1–4] to improve the visual quality of images. Data hiding methods have also been introduced to perform CE while embedding data into images. Reference [5–13] propose data-hiding methods that aim to improve image quality while ensuring data exclusivity and integrity. However, data embedding methods embed data permanently without allowing recovery of the original images. Reversible data hiding (RDH) methods with CE were proposed to enhance image contrast simultaneously and perform data embedding while recovering original images losslessly. Lossless compression [14,15], difference expansion (DE) [12,13], histogram shifting (HS) [16,17], and prediction error expansion (PEE) [18,19] are the four main types of frequently used methods for which RDH is best known. RDH with image contrast enhancement, in contrast to traditional image processing techniques, achieves histogram equalization (HE) during the data embedding process while still allowing for the recovery of hidden data after embedding. Enhancing an image's contrast has been made easier with the help of histogram equalization (HE) [20]. It allows an adjustment of the image intensity to enhance contrast by allocating the intensity values of pixels in the input image so that the output image contains a uniform distribution of intensities while improving contrast. Global histogram equalization, local histogram equalization, or fast quadratic dynamic histogram equalization are used to equalize histograms based on the execution time [21]. Traditional CE with RDH methods primarily focus on grayscale images. For color images, RDH with CE algorithms is comparatively uncommon. Taking a standard RGB image as an example, it has three color dimensions R, G and B. It contains more information than grayscale images, making modifying it more troublesome. The traditional RDH algorithm can be applied in each dimension of the RGB image. Due to the large correlation between the three-dimensional matrices of the color image, making completely irrelevant modifications to the three dimensions will distort the color of the image, resulting in a decrease in image quality. In this study, we propose a new RDH with contrast enhancement for color images ensuring the image's visual quality with high embedding capacity.

Every reversible data-hiding algorithm aims to satisfy two key requirements: an increase in embedding capacity and preserving all image details. Many RDH with contrast enhancement techniques have been adopted to meet the requirements, including improving the enhancement effect, observing it, and finding the enhancement and its use as a development of medical imaging. Wu et al. [22] were the first to propose an RDH with contrast enhancement. Histogram equalization is accomplished by repeatedly shifting the histogram. However, as the number of repeats rises, more bins are combined, increasing repetitions, resulting in an artefact known as an intensity mismatch. This artefact is typically only noticeable with a significant amount of histogram shifting, but it can be seen with just a few repetitions for some particular images. In conclusion, the approach necessitates a pre-processing step that yields intensity mismatched artefacts, and the ideal number of histogram shifting repeats cannot be established. In 2017, A high-capacity RDH algorithm for contrast enhancement of medical images based on regions of interest (ROI) was proposed by Yang et al. [23]. This algorithm first used an "adaptive threshold detector" (ATD) segmentation algorithm to automatically separate the ROI from the "region of non-interest" (NROI), then enhanced the contrast of the ROI by stretching the grayscale, and finally embedded the data into the bins of the stretched histogram. Finally, the remaining substantial amount of data will be incorporated into the NROI, quality or not. The first reversible data hiding with automatic contrast enhancement was proposed by Kim et al. [24] for Automatic Image Enhancement (AIE). The method shows that a contrast enhancement based on reversible data hiding offers file-saving functionality for automatic image enhancement because the original image can be restored right away from the enhanced image. While simultaneously creating a location map, it employs unidirectional histogram shifting repeatedly. In contrast to Wu et al. [25], Kim et al. [24] stretched the distortion across the entire pixel range, which localized the distortion by combining the bins near the boundary bins. To maximize the effect of histogram equalization per the image's content, the number of repetitions is not manually specified; instead, it is adaptively chosen. This yield results comparable to global histogram equalization techniques, which are useful for enhancing low-contrast images but are not always appropriate for everyday usage since they may overly increase contrast. Gao et al. [26] proposed a controlled contrast enhancement approach for enhanced visual quality.

Data hiding in the spatial domain and the integer wavelet transform (IWT) domain are two separate stages that make up the data hiding technique. To prevent excessive contrast enhancement, the Relative Contrast Error (RCE) is used to restrict the number of embedding rounds. An appropriate RCE threshold is given to obtain a satisfactory contrast stretch upper boundary. The original contrast is slightly increased throughout the data-concealing process. Chen et al. [27] proposed an RDH using a contrast enhancement approach called PAB. There are two steps to the data embedding process: the histogram shifting stage and the pixel value ordering (PVO) stage. The histogram is automatically shifted as a result of the histogram distribution, which is adaptive so that the designated gravity center is close to the middle of the intensities after embedding. Then, by limiting the range of pixel change, bidirectional histogram pre-shifting is used to reduce visual distortion. Utilizing the Pixel Value Ordering (PVO) approach at the initial step of contrast enhancement increases the embedding capability even further. Gao et al. [28] proposed an automatic contrast enhancement method utilizing bi-histogram shifting. Exploiting the brightness preservation (BP) method, the proposed scheme adaptively selects two peak bins and two lower bins based on four conditions based on the image brightness. The lower bins are combined, while the two peak bins are used for splitting and embedding. The proposed method's results reveal high embedding capacity and sufficient contrast enhancement.

Although several lossless CE methods have been proposed for grayscale images, only a few apply to color images. Nowadays, color images are popularly used and transmitted because a color image is a powerful visual descriptor and contains more information than a grayscale image [22]. Kim et al. [29] proposed Uniform contrast enhancement (UCE) of RGB channels. The proposed method consistently applies CE methods to each RGB channel. Then it combines them to generate the marked color image instead of directly applying CE methods to the color images. The proposed method selects the smallest maximum number of iterations among the three channels to be the number of repetitions applied to all the channels. The RGB channels are subject to an equal number of iterations. When additional histogram bins are modified, this approach produces visual distortions in images while preventing over-enhancement in one or two channels. A new RDH-based contrast enhancement employing the HSV (hue, saturation, and value) color model was proposed by Wu et al. [22]. The proposed method converts the RGB channels to Max, Median, and Min channels based on numerical values of red, green, and blue colors. Using a lossless contrast enhancement technique described in [30], the Max channel is improved while the Median and Min channels are changed to maintain their ratios.

The proposed strategy preserves the hue and saturation (hue and saturation preserving, HSP) components while retrieving the original image, preventing color distortions. Although the image quality is enhanced, this method limits embedding capacity. Amoah et al. [31] proposed a new UCE for color images. The proposed method consistently uses bi-histogram shifting, explained in [28], to improve the contrast in each channel of the RGB image before combining them to build the marked color image. The bi-histogram shifting procedure is repeated using the smallest possible repeats among the three channels. Although compared with the first UCE, the resulting image appears better enhanced, the visual quality of the resulting image remains poor. A new RDH with contrast enhancement for color images is proposed in this study to increase the size of embedding capacity while achieving the best contrast enhancement.

2 Related Work

2.1 Uniform Contrast Enhancement (UCE)

Uniform contrast enhancement (UCE) is a method proposed by Kim et al. [29]. First, the proposed method separates a color image into three channels, red, green, and blue (RGB), and assigns an equivalent number of histogram shifting iterations on each channel. The potential maximum number of repetitions of all the channels is first calculated, and the minimum between the number of repetitions of all channels is used for histogram shifting, data embedding, and contrast enhancement.

$$p_i'' = \begin{cases} p_i' + b_k, & p_i' = P_s \\ p_i' + 1, & P_s < p_i' < P_c \\ p_i', & otherwise \end{cases} \quad (1)$$

where p_i' is the i^{th} pixel value in the image, p_i'' is the pixel value after histogram shifting of p_i'. P_S is the bin that needs to be embedded, P_C is the bin that needs to be combined, and b_k is the secret information that needs to be embedded in the k^{th} bit, and its value is 0 or 1. RHS is applied if $P_S \prec P_C$, LHS otherwise.

Before each histogram shifting, a vector $L = (L_1, \ldots, L_m, \ldots)$ to record P_c and the information of the adjacent bins are required. d is used to direct the histogram shifting either RHS if $d = 1$, or LHS if $d = -1$. When $p_i' = P_C$, $L_m = 0$; when $p_i' = P_C - d$, $L_m = 1$.

Different from other RDH algorithms, this algorithm requires that the difference between the brightness of the enhanced image and the brightness of the original image is not greater than 1, and the brightness of the defined image is the mean value of all pixels in the image. When the brightness of the original image is greater than the brightness of the enhanced image, RHS is applied, In addition to apply LHS. P_S is selected as the pixel value with the largest number of pixel value ranges in J_{P_S}, and J_{P_S} is dynamically selected according to the brightness difference between the original image and the enhanced image. P_C is defined as the number of pixels contained in a pixel value within a certain range and its adjacent pixel values the number sums the minimum pixel value.

2.2 Hue Saturation Preservation (HSP)

Wu et al. [22] proposed an HSP technique based on finding the maximum, median, and minimum values among the RGB image's three channels. Then, the histograms of the three are combined. The original image is next converted to HSV. How the conversion is done is demonstrated in the following equations.

$$H = \begin{cases} 60x\left(\frac{G-B}{X-Z}\right), X = R \\ 60x\left(\frac{B-R}{X-Z} + 2\right), X = G \\ 60x\left(\frac{R-G}{X-Z} + 4\right), X = \\ undefined, X = 0 \end{cases} \quad (2)$$

$$S = \begin{cases} \frac{X-Z}{X}, X \neq 0 \\ 0, X = 0 \end{cases} \quad (3)$$

$$V = X \tag{4}$$

where X and Z represent the maximum and minimum of each pixel in the RGB model and Y the median.

HSP applies pre-processing to avoid histogram overflow during data embedding. First, move all empty histogram bins of the X channel mentioned in Eq. (2) to the far left of the histogram, and the modified X channel, Y channel and the Z channel are combined to obtain a total histogram, and the merging operation is to merge the bin with the lowest height in the histogram to the adjacent bin. After the merging is completed, the total histogram can be disassembled to obtain the histogram of the three channels after pre-processing. The bookkeeping information records the extra information generated by all previous operations.

During embedding, two bins f_L and f_R are first found, secret information is embedded into X channel by splitting the 2 highest bins and achieving histogram equalization. To ensure the image quality, Y channel and Z channel are modified based on exploiting Eqs. (5)–(6).

$$Y' = X' - (X - Y) \tag{5}$$

$$Z' = X' - (X - Z) \tag{6}$$

where X' represents the modified X channel, Y' and Z' represent respectively the modified Y channel and Z channel. Y' and Z' are stored using information bookkeeping for recovery purposes.

3 Proposed Method

An automatic contrast enhancement (ACE) approach for color images using the RGB (red, green, and blue) color model is proposed in this study. In contrast to methods employed in [31] which applied an equalized number of repetitions on all channels of the RGB image to enhance the image and embed data, a non-equalized number of repetitions is applied, and each channel is adjusted after embedding secret bits to provide good image quality. Maximum (Max), Median (Med), and Minimum (Min) channels are the categories used to categorize the channels of the image to achieve different numbers of repetitions. Every dimension of a color image, a three-dimensional matrix, is a channel, either R, G, or B, which might be Max, Med or Min based on image structure. Hence, we focus on determining which channel is Max, Med or Min by summing each channel's pixel values and comparing each summation result. Afterwards, we find the potential number of iterations for each channel.

3.1 Number of Repetitions

Three cases are defined with sub-cases by exploiting the Max Channel to determine the number of repetitions applied for each channel while embedding secret bits.

Case 1: If R is max, we maintain all possible repetition numbers for R and Min channels to embed data. Then a comparison is made between the other two channels to find the Med and Min. The ratio between the Max and Med Channels is first calculated, then the number of iterations for the Med channel. Eqs. (7) and (8) demonstrate how to calculate the ratio, and the number of repetitions in case G is the Med channel, and B is the Min channel:

$$G_{ratio} = \frac{G_{sum}}{R_{sum}} \tag{7}$$

$$G_{rep} = \lceil (1 - G_{ratio}) \times G_{\max - rep} \rceil \tag{8}$$

where $\lceil . \rceil$ denotes the round operation, G_{sum} and R_{sum} are the summation of pixels values respectively of the G channel and R channel, and $G_{\max -rep}$ the maximum obtained a number of iterations for the G channel. Suppose B channel appears to be the Med. In that case, we maintain the potential number of iterations found for the G channel while calculating the number of iterations applied for the B channel by using its ratio between B and R, i.e., Med and Max channels as shown in Eqs. (9) and (10)

$$B_{ratio} = \frac{B_{sum}}{R_{sum}} \tag{9}$$

$$B_{rep} = \left\lceil (1 - B_{ratio}) \times B_{\max -rep} \right\rceil \tag{10}$$

where $\lceil . \rceil$ denotes the round operation, B_{sum} and R_{sum} are the summation of pixels values respectively of B channel and R channel, and $B_{\max -rep}$ the maximum obtained number of iterations for the B channel.

Case 2: The same steps are exploited as in Case 1 if G is Max. As a result, the G channel and B channel will maintain the potential number of iterations if the B channel is Min, and only the one of R will change by using the Eqs. (11) and (12)

$$R_{ratio} = \frac{R_{sum}}{G_{sum}} \tag{11}$$

$$R_{rep} = \left\lceil (1 - R_{ratio}) \times R_{\max -rep} \right\rceil \tag{12}$$

where $\lceil . \rceil$ denotes the round operation, R_{sum} and G_{sum} are the summation of pixels values respectively, of the R channel and G channel, and $R_{\max -rep}$ the maximum obtained number of iterations for the R channel. If B is Med Channel and R is Min Channel, G and R will keep the potential number of iterations, and only one of B will change by applying Eqs. (13) and (14)

$$B_{ratio} = \frac{B_{sum}}{G_{sum}} \tag{13}$$

$$B_{rep} = \left\lceil (1 - B_{ratio}) \times B_{\max -rep} \right\rceil \tag{14}$$

Case 3: If B is Max, the same process is applied as in case 1. Hence, if R is the Med channel and G is the Min channel, the B channel and G channel will keep the previously obtained number of repetitions, and only one of R will change by applying the Eqs. (15) and (16)

$$R_{ratio} = \frac{R_{sum}}{B_{sum}} \tag{15}$$

$$R_{rep} = \left\lceil (1 - R_{ratio}) \times R_{\max -rep} \right\rceil \tag{16}$$

where $\lceil . \rceil$ denotes the round operation, R_{sum} and B_{sum} are the summation of pixels values respectively of R channel and B channel, and $R_{\max -rep}$ the maximum obtained number of iterations for the R channel. If the G channel is Med and R channel, the Min, B channel, and R channel will keep their potential max number of iterations, and only the one of B will change by applying the Eqs. (17) and (18)

$$G_{ratio} = \frac{G_{sum}}{B_{sum}} \tag{17}$$

$$G_{rep} = \left\lceil (1 - G_{ratio}) \times G_{\max -rep} \right\rceil \tag{18}$$

3.2 Data Hiding and Embedding

With the exception of utilizing a different number of repetitions for the Median Channel, we apply the strategy in [31] employed to embed secret bits. The following algorithm reveals the description of the embedding process.

Algorithm 1 Embedding procedure

Embedding procedure
Input: Original RGB image $\{P_y\}_{y=1}^{I}$ and payload
Output: Contrast enhanced image $\{P''_y\}_{y=1}^{I}$
1: Set $\{P''_y\}_{y=1}^{I} = \{P_y\}_{y=1}^{I}$
2: Separate the RGB image into R, G and B channels
3: Find Max, Med, and Min channels
4: Find $R_{\max-rep}$, $G_{\max-rep}$ and $B_{\max-rep}$
5: Compute R_{rep},G_{rep} and B_{rep}
6: Apply bi-histogram shifting separately on each RGB channel
7: Adjust obtained images resulting from each channel
8: Set $\{P'_y\}_{y=1}^{I} = \{P''_y\}_{y=1}^{I}$
9: Build marked image by combining enhanced R, G, and B channels

3.3 Image Adjustment

When hidden data is processed, bits are embedded in all channels, and most pixel values appear to be either extremely low or extremely high, which causes distortions in the image. The proposed method gives out a solution by adjusting the image with no loss of data embedded. The first step to adjusting an image consists of extracting channels of the original image. Secondly, each pixel of the original channel is added to the corresponding pixel of the enhanced channel, then we round the result divided by 2 to have a coefficient used to obtain the adjusted pixel. Let's consider $P_{i,j}$ a pixel from the original channel before enhancement, $P'_{i,j}$ a pixel from the enhanced channel, and $P''_{i,j}$ a pixel of the adjusted channel. $P''_{i,j}$ is obtained by applying Eq. (19):

$$P''_{i,j} = P'_{i,j} - C_{i,j} \tag{19}$$

where $C_{i,j}$ denotes the coefficient of adjustment of the pixel $P'_{i,j}$. $C_{i,j}$ is obtained using the following equation:

$$C_{i,j} = \lceil P'_{u,j} - \left(P_{i,j} + C_{i,j}\right)/2 \rceil \tag{20}$$

where $\lceil . \rceil$ denotes the round operation.

3.4 Data Extraction and Image Recovery

The proposed method, as aforementioned, carries out data embedding, contrast enhancement, and the opposite process, which entails data extraction and image recovery. The original image is an additional tool in the proposed method's data extraction and image recovery processes. The adjusted enhanced image is first divided into three channels. To acquire the coefficient taken from the LSB of the adjusted pixels, each channel's composing pixel is compared to the original channel pixel. The improved pixel with embedded data is then obtained. The original image is restored following data extraction using the methods described in [31]. To illustrate the data extraction and image recovery workflow, an illustration is proposed. Let's consider $P_{i,j} = 99$, $P'_{i,j} = 90$, using Eq. (20), $C_{i,j} = -5$. Hence, by exploiting Eq. (19), we obtain $P''_{i,j} = 95$. When $P''_{i,j}$ is compared to $P_{i,j}$, we get 9 to be close to the double 5. Hence, we extract five from $P''_{i,j}$ to obtain $P'_{i,j}$. Then from $P'_{i,j}$ we perform data extraction and image recovery following the steps in [31].

4 Experimental Results and Analysis

Random images of sizes 512 × 512 and 768 × 512 issued from the USC image set, Kodak Lossless True Color Image Suite image set, and other image sets, respectively, are used to assess the efficiency of the proposed method. In this experiment, a fair comparison with the method proposed in [29,31] and [32] is established by utilizing the same amount of data to be embedded.

The effectiveness of the proposed method will be assessed and compared using metrics classified in subsections as follow:

1. The first subsection establishes a comparative analysis of the contrast enhancement between the proposed method and prior methods using the relative contrast error (RCE) as a comparison metric.
2. The second subsection reveals the image quality of the proposed method and methods in [29,31], and [32] by using metrics such as peak signal-to-noise ratio (PSNR), Structural similarity index (SSIM), relative mean brightness error (RMBE) of the different methods.
3. The third subsection analyses the color difference.

In the last subsection, the embedding capacity of the various methods are compared.

4.1 Contrast Enhancement

The relative contrast error (RCE) computed between the original and enhanced image is used to assess the CE effect. RCE = 0.5 means the image contrast is unchanged, whereas RCE > 0.5000 denotes improved image contrast. In Table 1, the RCE resulting from all the methods applied in the Kodak Lossless True Color Image Suite Image set is greater than 0.5000. This means that the proposed method can perform contrast enhancement. In Table 2, the RCE of the images from USC image set are less than 0.5000 when applying methods using HSP based algorithm. However, the proposed method in all images of the USC image set outperformed in contrast enhancement. As a result, Table 4 displaying the average result of RCE and other metrics of performance reveals that the proposed method keeps the RCE greater than 0.5000 showing how it performs better contrast enhancement than some existing methods.

Table 1: Comprehensive evaluation using Kodak Lossless True Color Image Suite image set

Methods	Image	PSNR	SSIM	RCE	RMBE	Embedding rate	CIEDE2000
[29]	Kodim01	41.25	0.97	0.5036	0.99	0.27	6.00
	Kodim02	39.53	0.98	0.5006	0.99	0.87	6.39
	Kodim04	40.89	0.96	0.5113	0.99	0.25	6.22
	Average	**40.55**	**0.97**	**0.5051**	**0.99**	**0.46**	**6.20**
[31]	Kodim01	41.30	0.96	0.5047	0.97	1.29	6.05
	Kodim02	39.56	0.97	0.5036	0.96	1.35	6.66
	Kodim04	42.29	0.92	0.5263	0.92	4.73	7.12
	Average	**41.05**	**0.95**	**0.5115**	**0.95**	**2.45**	**6.61**
[32]	Kodim01	36.10	0.99	0.5086	0.99	0.10	1.27ss
	Kodim02	35.87	0.98	0.5024	0.99	0.28	1.03
	Kodim04	35.55	0.99	0.5076	0.99	0.08	1.26
	Average	**35.84**	**0.98**	**0.5062**		**0.15**	**1.18**

(Continued)

Table 1: Continued

Methods	Image	PSNR	SSIM	RCE	RMBE	Embedding rate	CIEDE2000
Proposed method	Kodim01	41.45	0.94	0.5298	0.99	0.90	7.15
	Kodim02	39.54	0.99	0.5125	0.98	3.86	6.37
	Kodim04	42.85	0.98	0.5287	0.97	1.12	6.20
	Average	**41.28**	**0.97**	**0.5236**	**0.98**	**2.02**	**6.57**

Table 2: Comprehensive evaluation on USC image set

Methods	Image	PSNR	SSIM	RCE	RMBE	Embedding rate	CIEDE2000
[29]	USC03	43.20	0.75	0.5002	0.99	1.14	6.12
	USC05	43.59	0.97	0.5001	0.99	0.68	6.57
	USC06	43.56	0.92	0.5061	0.99	0.35	5.59
	USC08	44.41	0.97	0.4992	0.99	0.7	6.68
	USC10	42.95	0.97	0.5000	0.99	0.14	6.45
	Average	**43.54**	**0.91**	**0.5011**	**0.99**	**0.60**	**6.28**
[31]	USC03	43.03	0.66	0.5190	0.98	5.47	6.33
	USC05	43.42	0.94	0.5019	0.97	2.46	6.28
	USC06	43.84	0.88	0.5046	0.96	1.18	6.23
	USC08	44.05	0.95	0.5038	0.98	2.6	6.61
	USC10	42.84	0.99	0.5000	1.00	0.04	6.32
	Average	**43.43**	**0.88**	**0.5058**	**0.97**	**2.35**	**6.35**
[32]	USC03	32.09	0.97	0.4880	0.99	0.51	1.43
	USC05	19.85	0.93	0.5505	0.93	1.27	7.66
	USC06	21.54	0.93	0.4369	0.99	0.20	5.2
	USC08	16.71	0.81	0.5782	0.92	1.58	10.06
	USC10	25.03	0.96	0.4874	0.96	0.06	3.10
	Average	**23.04**	**0.92**	**0.5082**	**0.95**	**0.72**	**5.49**
Proposed method	USC03	43.09	0.74	0.5194	0.99	2.32	6.60
	USC05	43.47	0.98	0.5058	0.99	1.65	6.51
	USC06	43.56	0.93	0.5100	0.99	0.93	5.77
	USC08	44.28	0.98	0.5077	0.99	1.73	6.75
	USC10	42.93	0.98	0.5139	0.99	0.07	6.39
	Average	**43.46**	**0.92**	**0.5113**	**0.99**	**1.34**	**6.40**

4.2 Image Quality

The effectiveness of the image quality is assessed by employing metrics such as Peaked Signal-to-Noise Ratio (PSNR), Structural Similarity index (SSIM) and Relative Mean Brightness Error (RMBE). The PSNR ratio measures the strength of a signal in relation to its noise power. In addition, a higher PSNR indicates less noise added to the original image. SSIM calculates the similarities between the original and enhanced images and gives values from 0 to 1, with 1 indicating that the images are identical. RMBE calculates the difference in average brightness between the original and improved images. Tables 1, 2 and 3 show the numerical results of PSNR, SSIM and RMBE. The proposed method achieves a higher average PSNR and SSIM values in all the images than other methods. Figs. 1 and 2 display the enhanced images using different methods.

Table 3: Comprehensive evaluation on other image set

Methods	Image	PSNR	SSIM	RCE	RMBE	Embedding rate	CIEDE2000
[29]	4.2.05	45.46	0.91	0.4992	0.97	0.54	5.56
	House	44.39	0.96	0.5001	0.99	0.3	6.55
	Average	**44.92**	**0.93**	**0.4996**	**0.98**	**0.42**	**6.05**
[31]	4.2.05	45.31	0.87	0.5005	0.96	1.51	5.13
	House	43.98	0.91	0.4989	0.94	0.8	6.07
	Average	**44.64**	**0.89**	**0.4997**	**0.95**	**1.155**	**5.6**
[32]	4.2.05	15.80	0.83	0.5924	0.90	0.48	10.86
	House	28.89	0.98	0.4944	0.97	0.18	1.91
	Average	**22.34**	**0.90**	**0.5434**	**0.93**	**0.33**	**6.38**
Proposed method	4.2.05	45.38	0.83	0.5190	0.99	1.13	6.57
	House	44.22	0.98	0.5285	0.99	0.60	6.44
	Average	**44.8**	**0.90**	**0.5237**	**0.99**	**0.86**	**6.50**

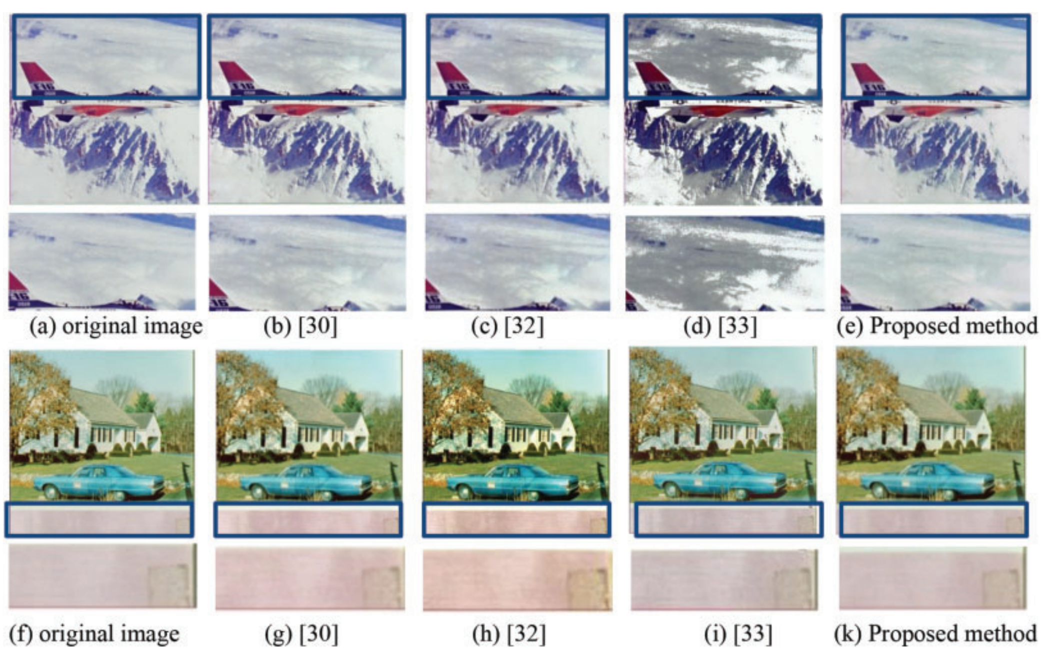

Figure 1: Images 4.2.05 and house enhanced by the proposed method and different prior methods

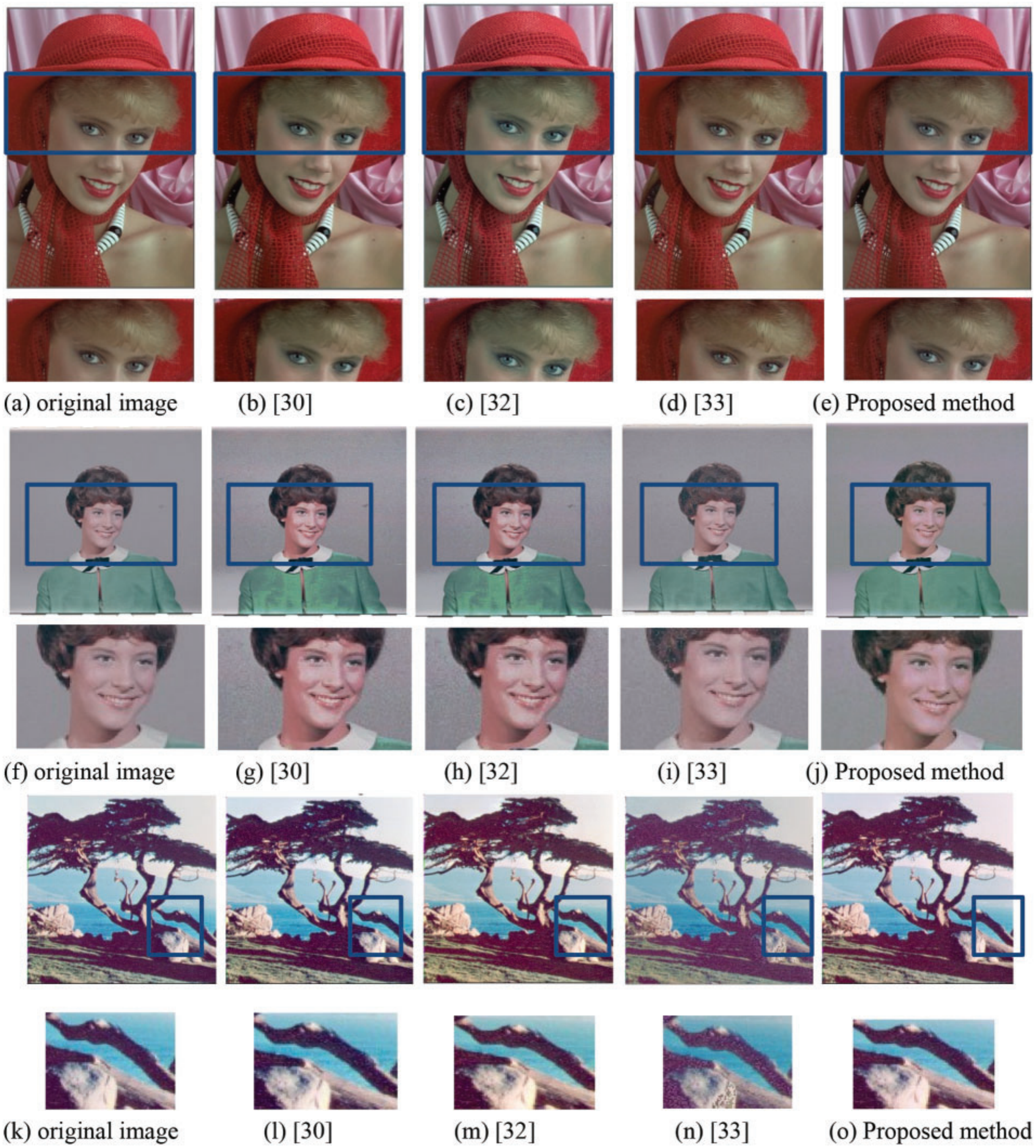

Figure 2: kodim04, USC03 and USC06 from Kodak Suit and USC image sets enhanced by the proposed method and different prior methods

The selected area in blue on Figs. 1, and 2 are displayed separately from the enhanced images. This shows the physical difference between the proposed and earlier methods acquired visual quality. In comparison to the clouds from the image enhanced by previous methods, the clouds in the selected area obtained by the enhancement of 4.2.05 by the proposed method are whiter and brighter. Meanwhile, some methods change the color of clouds to a deep gray. The wall on the image of the house, which was enhanced by UCE and bi-histogram shifting, has a somewhat incorrect yellow tint, while the propose method enhances the white on the wall. The black circle around the eyes is darker and looks greener on Kodim04, enhanced in Figs. 1b–1d. While using [32] and the proposed method, there is no visible greener appearance, however, kodim04 is greatly enhanced. When enhancing USC03, more extra distortions are added to the image, giving it a 3D appearance.

The enhanced USC03 in Fig. 2i resembles the original image, demonstrating that no contrast enhancement was performed. The color of the background in the last displayed image was altered during data embedding, but the proposed method makes the tree appear much more realistic. The proposed method successfully produces contrast enhancement for color images of all the image sets. Table 4 summarizes the average result of metrics of performance used to assess the proposed method image quality.

Table 4: Average result of metrics of performance

Metrics	[29]	[31]	[32]	Proposed method
PSNR	43.00	43.04	27.07	43.73
SSIM	0.93	0.90	0.93	0.93
RCE	0.5019	0.5056	0.5192	0.5154
RMBE	0.98	0.95	0.62	0.98
Embedding rate	0.49	1.98	0.40	1.38
CIEDE2000	6.17	6.18	4.35	6.45

4.3 Color Preservation

The CIEDE2000 is frequently used to access color preservation and color distortion. The value is anticipated to be as low as possible to prevent color distortion. However, if the CIEDE2000 value is 0, the original image and the enhanced are the same. Table 4 shows the overall CIEDE2000 outcome. The proposed approach fails in maintaining color. But compared to other methods, Tables 1, 2 and 3 reveal that colors of some images have been successfully maintained by the proposed method after enhancement.

4.4 Embedding Rate

UCE as well as the method in [31] used to make a comparative analysis with the proposed method embeds data by repeating the histogram shifting. All the methods are given the same number of repetitions of 40, and then the proposed method applies changes based on its algorithm. To make fair the comparison with the method in [32], the same amount of data is given to all the images to embed and complete the analysis of the embedding rate. The column title embedding rate in different tables reveals the proposed method's embedding performance and prior ones. The overall results reveal that the method in [31] embeds more data than the other methods. However, the proposed method does not rank last in the embedding rate. Hence the embedding rate of the proposed method can be considered reasonable.

5 Conclusion

In this study, a novel reversible data hiding strategy for color images was presented. This scheme applies the bi-histogram shifting to embed data and adjusts the image to improve contrast. The original image is initially split into three channels using the RGB color model to identify the Max, Med, and Min channels. Before applying bi-histogram shifting, the Max channel conditions the number of iterations. After data are embedded in channels, the resulting images are adjusted to produce the marked image with better visual quality and high embedding capacity. When evaluated using PSNR, SSIM, RCE, RMBE, and CIEDE2000, the experimental results demonstrate that the enhanced images produced by the proposed method are qualitatively and aesthetically superior to those produced by several prior methods. The embedding rate attained using the advised method is suitable.

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