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Article

A Bi-Histogram Shifting Contrast Enhancement for Color Images

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Abstract: Recent contrast enhancement (CE) methods, with a few exceptions, predominantly focus on enhancing gray-scale images. This paper proposes a bi-histogram shifting contrast enhancement for color images based on the RGB (red, green, and blue) color model. The proposed method selects the two highest bins and two lowest bins from the image histogram, performs an equalized number of bidirectional histogram shifting repetitions on each RGB channel while embedding secret data into marked images. The proposed method simultaneously performs both right histogram shifting (RHS) and left histogram shifting (LHS) in each histogram shifting repetition to embed and split the highest bins while combining the lowest bins with their neighbors to achieve histogram equalization (HE). The least maximum number of histograms shifting repetitions among the three RGB channels is used as the default number of histograms shifting repetitions performed to enhance original images. Compared to an existing contrast enhancement method for color images and evaluated with PSNR, SSIM, RCE, and RMBE quality assessment metrics, the experimental results show that the proposed method's enhanced images are visually and qualitatively superior with a more evenly distributed histogram. The proposed method achieves higher embedding capacities and embedding rates in all images, with an average increase in embedding capacity of 52.1%.

Keywords: Contrast enhancement; bi-histogram shifting; histogram equalization

1 Introduction

This paper aims at improving the proposed method in [1] by applying a novel automatic contrast-enhancement (CE) method for grey-scale images uniformly on each RGB (red, green, and blue) channel of color images. In this paper, the proposed method replaces the existing grey-scale CE method used in [1] to improve images while maintaining the equalized number of repetitions across the channels. Traditionally, several proposed contrast enhancement methods aim at enhancing grey-scale images by adjusting the image brightness to enrich the layers of graphics and avoid images from being too dark or light. Several contrast enhancement methods are proposed in [2–7] to enhance the contrast of gray-scale images. Recently, lossless CE and reversible data hiding (RDH) has become an active research area in image processing because of their lossless property. Although many lossless contrast enhancement methods have been proposed in [8–18], only a few centers on color images.

Kim et al. [1] proposed a uniform contrast enhancement (UCE) method of RGB channels. Unlike directly applying contrast enhancement methods to the color images, the proposed method uniformly applies CE methods on each RGB channel and combines them to form the marked color image. The proposed method determines the number of repetitions using the smallest of the maximum number of repetitions among the three channels. It applies an equalized number of repetitions across the RGB channels. Although this method prevents over enhancement in one or two channels, it causes visual distortions in images when more histogram bins are modified. Wu et al. [19] proposed a new RDH-based contrast enhancement using the HSV (hue, saturation, and value) color model. The proposed method converts the RGB channels to Max, Median, and Min channels according to the numerical values of red, green, and blue colors. The Max channel is directly enhanced using a lossless contrast enhancement method described in [18], whereas the Median and Min channels are modified to maintain their ratios. In avoiding color distortions, the proposed method preserves the hue and saturation components while recovering the original image.

An improved method was proposed in [20] to resolve the inability to achieve complete image recovery. The proposed method similarly converts the RGB channels to Max, Median, and Min channels and applies a CE method on the Max channel. The proposed method introduces a new pre-processing for the original RGB values to prevent overflow and underflow. While keeping an unchanged difference between the Max, Median, and Min channels, the proposed method preserves the hue component and successfully recovers the original image. Li et al. [21] proposed an RDH method based on the prediction-error expansion, which improves prediction accuracy in one color channel by using edge information from other channels. While the proposed method increases prediction accuracy and decreases prediction-error entropy, current methods for using inter-channel correlations are far from optimal. Ou et al. [22] proposed a reversible data hiding method based on channel-dependent payload partition and adaptive embedding for color images. The proposed method divides the total payload and embeds it into each channel based on its prediction-error histogram (PEH), minimizing total embedding distortion. In [23], a contrast enhancement method is proposed using the gamma correction and a weighted probability distribution of luminance pixels to improve the contrast and brightness of digital images.

This paper proposes a bi-histogram shifting contrast enhancement for color images based on the RGB color model. The proposed method maintains a uniform number of repetitions among the RGB channels as in [1] but applies a bi-histogram shifting contrast enhancement method to enhance each RGB channel, then combines the channels to form the improved image. To evaluate the proposed method with the existing method in [1], only two randomly selected images from Kodak Lossless True Color Image Suite [24] and three randomly selected images from the USC standard [25] images are used for the experiments due to space limitation. The enhanced images generated by both methods demonstrate the proposed method's superior performance as it achieved better visual quality with higher embedding capacity. The main contributions of the proposed method include:

1. The proposed method achieves better visual quality with a more evenly distributed histogram.
2. The proposed method achieves higher embedding capacity in images while maintaining a better visual quality in images.

2 Method Description

This section will first introduce the uniform contrast enhancement (UCE) method in [1], followed by the proposed bi-histogram shifting contrast enhancement method based on the uniform RGB channel enhancement.

2.1 Uniform Contrast Enhancement (UCE)

Kim et al. [1] propose a uniform contrast enhancement method based on applying an equivalent number of histograms shifting repetitions on each RGB channel. The proposed method first calculates the maximum number of repetitions possible for each RGB channel, as shown in Eqs. (1)–(3) for the red channel.

$$R_{\max} = UCE \max H'_r \tag{1}$$

$$H'_r = \sum_{i=0}^{I} \| p'_i = r \| \tag{2}$$

$$\| p'_i = r \| = \begin{cases} 1 & \text{if } p'_i = r \\ 0 & \text{if } p'_i \neq r \end{cases} \tag{3}$$

where I and H'_r refer to the total number of pixels in the image and the number of pixel values equal to the red channel r, respectively. UCE refers to the CE method used in [1] to determine the maximum number of repetitions possible for the red channel. The maximum number of repetitions for the green channel is explained in Eqs. (4)–(6) as given below:

$$G_{\max} = UCE \max H'_g \quad (4)$$

$$H'_g = \sum_{i=0}^{I} \| p'_i = g \| \quad (5)$$

$$\| p'_i = g \| = \begin{cases} 1 & \text{if } p'_i = g \\ 0 & \text{if } p'_i \neq g \end{cases} \quad (6)$$

where I and H'_r refer to the total number of pixels in the image and the number of pixel values equal to the green channel g, respectively. UCE refers to the CE method used in [1] to determine the maximum number of repetitions possible for the green channel. The maximum number of repetitions for the blue channel is obtained using Eqs. (7)–(9):

$$B_{\max} = UCE \max H'_b \quad (7)$$

$$H'_b = \sum_{i=0}^{I} \| p'_i = b \| \quad (8)$$

$$\| p'_i = b \| = \begin{cases} 1 & \text{if } p'_i = b \\ 0 & \text{if } p'_i \neq b \end{cases} \quad (9)$$

where I and H'_r refer to the total number of pixels in the image and the number of pixel values equal to the blue channel b, respectively. UCE refers to the CE method used in [1] to determine the maximum number of repetitions possible for the blue channel. After calculating the maximum number of repetitions possible for each channel, the least of the repetitions is chosen and used as the default number of histograms shifting repetitions for the three RGB channels. This approach prevents over enhancement in one or two channels. Eq. (10) shows how the least maximum number of repetitions is selected.

$$S = \arg\min(R_{\max}, G_{\max}, B_{\max}) \quad (10)$$

where $R_{\max}$, $G_{\max}$, and $B_{\max}$ refer to the maximum number of repetitions for the red channel, green channel, and blue channel, respectively. S refers to the minimum number of repetitions among the three RGB channels. The proposed method then applies the gray-scale CE method presented in [1] at the same number of histograms shifting repetitions on each RGB channel using S and combines them to form the enhanced color image.

2.2 Proposed Method

This paper proposes a bi-histogram shifting contrast enhancement (CE) method for color images based on the RGB (red, green, and blue) color model. The proposed method similarly applies an equalized number of repetitions on the RGB channels but performs a novel contrast enhancement method other than the existing method in [1] to enhance each RGB channel, then combines the channels to form the enhanced image. Eqs. (11)–(13) show how the proposed method calculates the maximum number of repetitions possible for the red channel.

$$R_{\max} = BHSCE \max H'_r \quad (11)$$

$$H'_r = \sum_{i=0}^{I} \| p'_i = r \| \quad (12)$$

$$\| p'_i = r \| = \begin{cases} 1 & \text{if } p'_i = r \\ 0 & \text{if } p'_i \neq r \end{cases} \quad (13)$$

where I and H'_r refer to the total number of pixels in the image and the number of pixel values equal to the red channel r, respectively. $BHSCE$ refers to the proposed CE method used to determine the maximum number of repetitions possible for the red channel. The maximum number of repetitions for the green channel is explained in Eqs. (14)–(16) as given below:

$$G_{\max} = BHSCE \max H'_g \tag{14}$$

$$H'_g = \sum_{i=0}^{I} \left\| p'_i = g \right\| \tag{15}$$

$$\left\| p'_i = g \right\| = \begin{cases} 1 & \text{if } p'_i = g \\ 0 & \text{if } p'_i \neq g \end{cases} \tag{16}$$

where I and H'_r refer to the total number of pixels in the image and the number of pixel values equal to the green channel g, respectively. $BHSCE$ refers to the proposed CE method used to determine the maximum number of repetitions possible for the green channel. The maximum number of repetitions for the blue channel is obtained using Eqs. (17)–(19):

$$B_{\max} = BHSCE \max H'_b \tag{17}$$

$$H'_b = \sum_{i=0}^{I} \left\| p'_i = b \right\| \tag{18}$$

$$\left\| p'_i = b \right\| = \begin{cases} 1 & \text{if } p'_i = b \\ 0 & \text{if } p'_i \neq b \end{cases} \tag{19}$$

where I and H'_r refer to the total number of pixels in the image and the number of pixel values equal to the blue channel b, respectively. $BHSCE$ refers to the proposed CE method. The proposed method then finds the least maximum number of histograms shifting repetitions using Eq. (20) and uses it as the default number of histograms shifting repetitions across the three RGB channels.

$$S = \arg\min(R_{\max}, G_{\max}, B_{\max}) \tag{20}$$

The proposed method selects the two highest bins and the two lowest bins from the image histogram to perform contrast enhancement and data embedding. The two highest bins are used as embedding and splitting bins, while the lowest bins are combined with their neighbors. The proposed method performs S repetitions of both right histograms shifting (RHS) and left histogram shifting (LHS) simultaneously in each histogram shifting repetition to achieve contrast enhancement and data embedding. Fig. 1 gives a graphical representation of the proposed bi-histogram shifting.

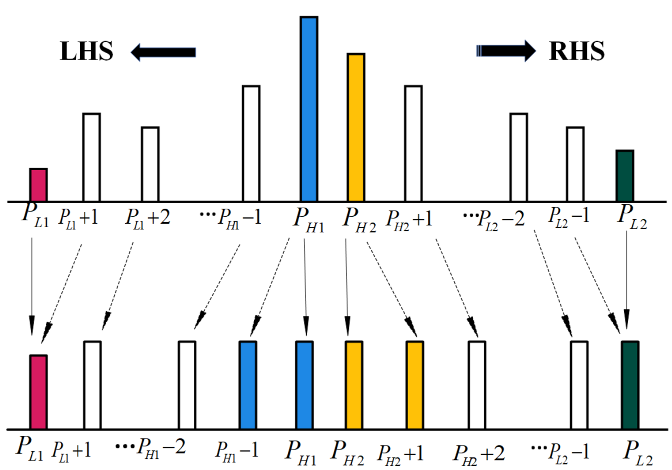


Figure 1: Diagram illustrating the proposed bi-histogram shifting

In Fig. 1, P_{H1} and P_{H2} refers to the two highest bins whiles P_{L1} and P_{L2} refers the two lowest bins. The proposed method sets P_{L1} and P_{L2} as combining bins and combines them with their adjacent bins to create space for the splitting and embedding bins P_{H1} and P_{H2} in every bi-histogram shifting. The splitting and embedding bins P_{H1} and P_{H2} are represented with blue and amber colors, respectively, while the combining bins P_{L1} and P_{L2} are represented with amaranth and aqua deep colors, respectively. The white bins represent the neighboring bins of P_{H1}, P_{H2}, P_{L1} and P_{L2} that are shifted in each bi-histogram shifting repetition. The proposed method performs right histogram shifting (RHS) and left histogram shifting (LHS) repetitions to create space to embed payload into P_{H1} and P_{H2} by combining P_{L1} and P_{L2} with their adjacent bins. The bi-histogram shifting with the embedding of the secret data are explained in Eqs. (21) and (22) as given below:

$$p_i'' = \begin{cases} p_i' - b_k & \text{if } p_i' = P_{H1} \\ p_i' - 1 & \text{else if } P_{L1} < p_i' < P_{H1} \\ p_i' & \text{else} \end{cases} \tag{21}$$

$$p_i'' = \begin{cases} p_i' + b_k & \text{if } p_i' = P_{H2} \\ p_i' + 1 & \text{else if } P_{H2} < p_i' < P_{L2} \\ p_i' & \text{else} \end{cases} \tag{22}$$

where $b_k \in \{0,1\}$ is the kth payload bit, Eqs. (11) and (12) show how the proposed method performs RHS and LHS simultaneously to shift, embed payload and split P_{H1} and P_{H2}. The proposed method sets p_i'' as the new p_i' before every repetition, whiles for the bi-histogram shifting, $(p_i')_{i=1}^{I} = (p_i)_{i=1}^{I}$. The repetition continues until the default number of iterations S is met. The proposed bi-histogram shifting is described in Algorithm 1.

Algorithm 1: Proposed method

Embedding procedure
Input: Original color image $\{p_i\}_{i=1}^{I}$ and payload.
Output: Marked image $\{p_i''\}_{i=1}^{I}$
1: Set $\{p_i'\}_{i=1}^{I} = \{p_i\}_{i=1}^{I}$
2: Find $R_{\max}$, $G_{\max}$, and $B_{\max}$. Calculate $\arg\min \; S$
3: Apply bi-histogram shifting separately on each RGB channel S times
4: Set $\{p_i'\}_{i=1}^{I} = \{p_i''\}_{i=1}^{I}$
5: Construct marked image by combining enhanced RGB channels

3 Experimental Results

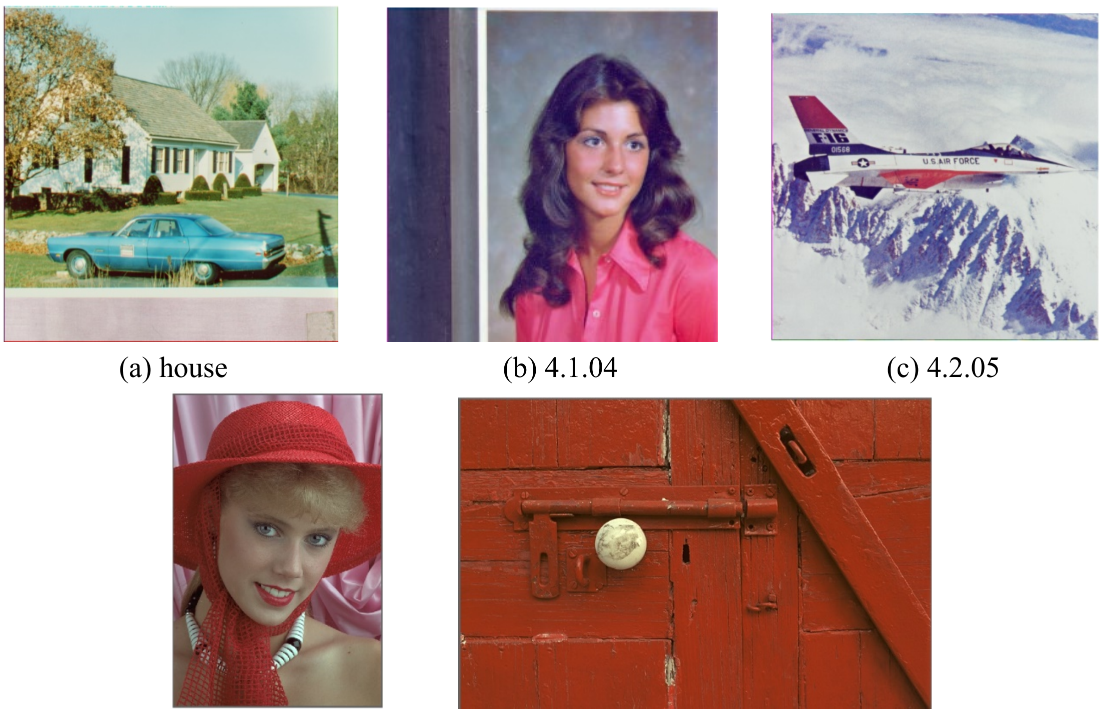
This section presents the experimental results and analysis of the proposed bi-histogram shifting contrast enhancement method and the uniform contrast enhancement (UCE) method in [1] when applied equally on the RGB channels. In the experiments, only two randomly selected images from Kodak Lossless True Color Image Suite [24] and three randomly selected images from the USC standard images [25] are used due to space limitation. The selected Kodak images are “kodim02” and “kodim04” with sizes of 768

× 512 or 512 × 768, and "4.1.04", "4.2.05", and "house" with sizes 512 × 512 from the USC website. The proposed method and UCE are compared with equal maximum repetitions to perform a fair analysis.

The experimental analysis and results are organized as follows:

1. The standard deviation reduction analysis of the enhanced images produced by both UCE and the proposed method is compared in the first subsection.
2. In the second subsection, four metrics: peak signal to noise ratio (PSNR), structural similarity (SSIM) index, relative contrast error (RCE), and relative mean brightness error (RMBE), are used as quality assessment metrics to evaluate the enhanced images of both the UCE and the proposed method.
3. The third subsection compares the embedding capacity and the embedding rate of the UCE and the proposed method when applied at the same number of repetitions S.

The five randomly selected standard images from Kodak Lossless True Color Image Suite and USC are shown in Fig. 2.



(a) house (b) 4.1.04 (c) 4.2.05

(d) kodim04 (e) kodim02

Figure 2: Original standard images from Kodak Lossless True Color Image Suite and UCE website

3.1 Standard Deviation Analysis

Standard deviation determines the quantitative estimation of contrast between the original and enhanced color image. The positive change in standard deviation reflects an enhancement in image contrast, while a negative change indicates a reduction in contrast. Fig. 3 shows the standard deviation of the enhanced images generated by UCE and the proposed method.

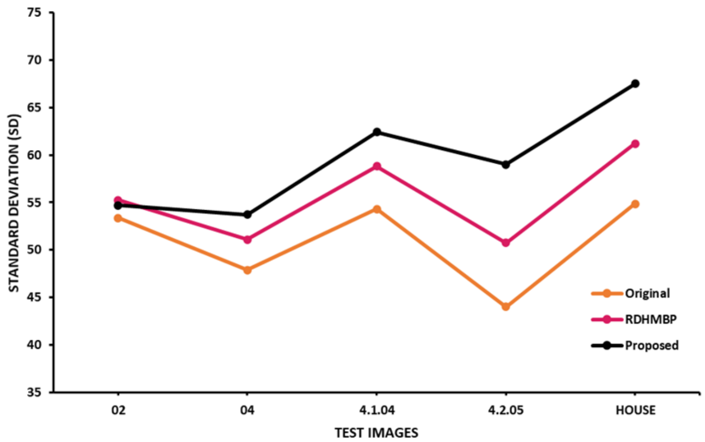
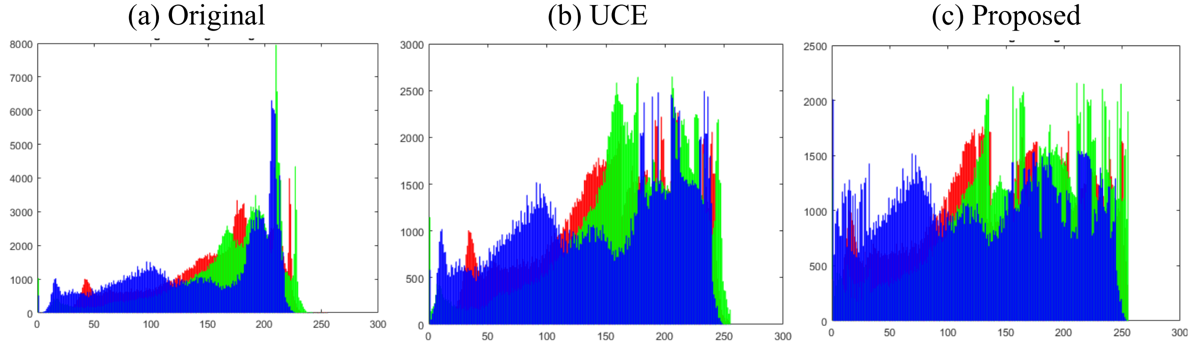


Figure 3: Comparison of the standard deviation of original and enhanced images generated by UCE and the proposed method

In Fig. 3, both UCE and the proposed approach achieve a positive change in standard deviation, indicating both methods enhance the contrast of the images. However, at the same number of repetitions, the proposed method improves the image contrast more than the UCE method, resulting in a higher numerical measure of image contrast. Despite the possibility of over-enhancement, Figs. 4(c), 4(f), 5(c) and 5(f) show that the proposed with a more uniformly distributed histogram achieves better visual quality. In principle, histogram equalization (HE) achieves contrast enhancement [26].

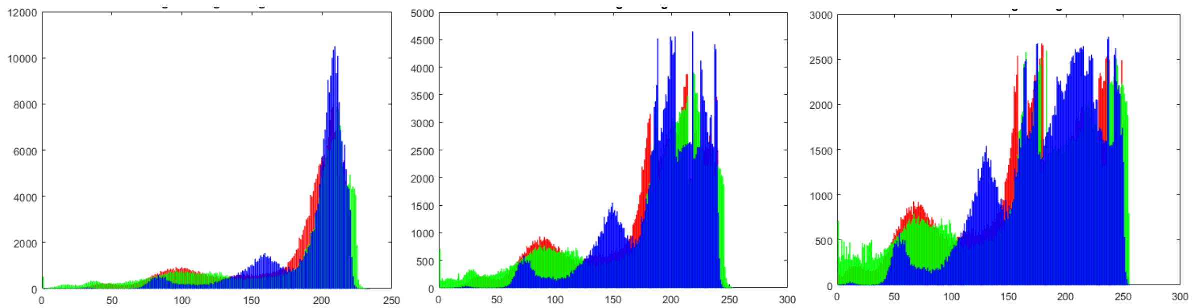
(a) Original (b) UCE (c) Proposed



(d) Original (e) UCE (f) Proposed

Figure 4: Original and enhanced images of "house" using UCE and the proposed method

(a) Original (b) UCE (c) Proposed



(d) Original (e) UCE (f) Proposed

Figure 5: Original and enhanced images of "4.2.05" using UCE and the proposed method

3.2 Metrics of Performance Assessment

In this paper, we use four quality assessment metrics: peak signal to noise ratio (PSNR), structural similarity (SSIM) index, relative contrast error (RCE), and relative mean brightness error (RMBE) to evaluate the enhanced images generated by the UCE and the proposed method. PSNR is the most widely used quality assessment model for measuring the quality of enhanced images. It is the ratio between a signal's maximum power and the power of the signal's noise. The structural similarity (SSIM) index is a perceptual metric that measures the similarities between the original and enhanced image. RCE uses standard deviation to compare the original and enhanced images for contrast enhancement. RCE values greater than 0.5 indicate an enhancement in image contrast, while values less than 0.5 indicate decreased image contrast. RMBE is used to measure the relative average brightness error between original and enhanced images. The evaluation results of UCE and the proposed method using the four quality assessment criteria are shown in Tabs. 1 and 2.

Table 1: Evaluation results for "kodim02", "kodim04", and "4.1.04"

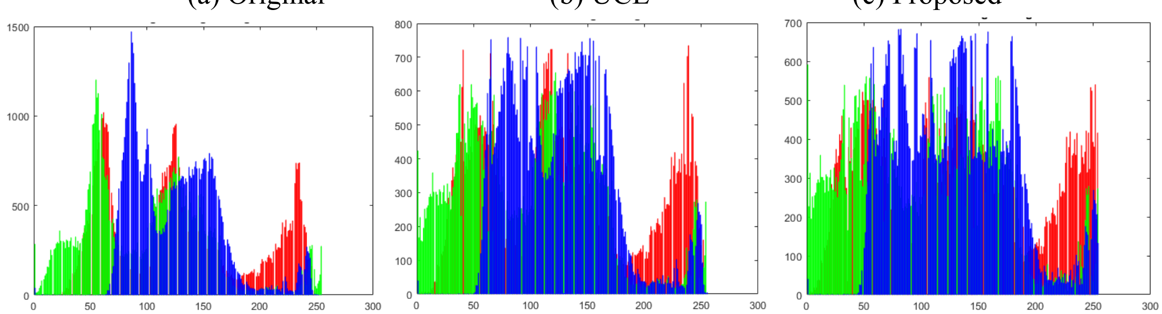
Method	Image	PSNR	SSIM	RCE	RMBE
	kodim02	39.49	0.97	0.50	0.96
UCE	kodim04	40.86	0.91	0.51	0.99
	4.1.04	42.34	0.93	0.52	0.99
	kodim02	39.55	0.96	0.51	0.99
Proposed	kodim04	41.31	0.92	0.52	0.98
	4.1.04	42.63	0.95	0.53	0.99

Table 2: Evaluation results for "4.2.05", and "house"

Method	Image	PSNR	SSIM	RCE	RMBE
UCE	4.2.05	45.49	0.87	0.53	0.98
	house	44.39	0.95	0.53	0.98
Proposed	4.2.05	45.18	0.86	0.56	0.97
	house	44.67	0.97	0.55	0.98

In Tabs. 1 and 2 evaluation results, it can be observed the proposed method outperforms the UCE method in most cases. The proposed method achieves a higher average PSNR, SSIM, and RCE values in all the images than UCE. Although the UCE method obtains higher RMBE values in "kodim04" and "4.2.05", the proposed method achieves the highest average RMBE values. Figs. 6–9 show the enhanced images of UCE and the proposed method when applied at the number of repetitions. The enhanced images of the proposed method have better visual qualities with a more uniformly distributed histogram than the UCE method.

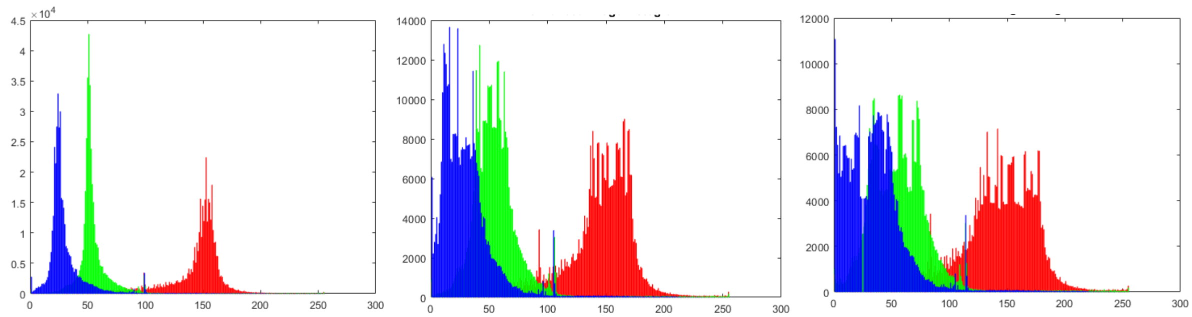
(a) Original (b) UCE (c) Proposed



(d) Original (e) UCE (f) Proposed

Figure 6: Original and enhanced images of "4.1.04" using UCE and the proposed method

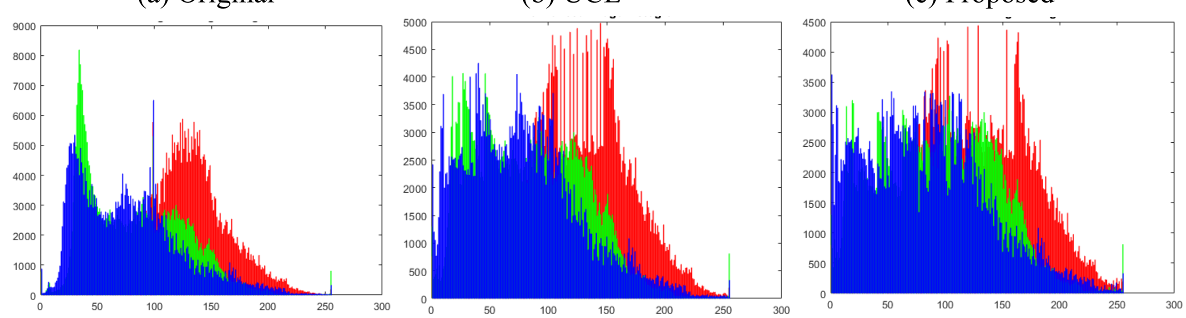
(a) Original (b) UCE (c) Proposed



(d) Original (e) UCE (f) Proposed

Figure 7: Original and enhanced images of "kodim02" using UCE and the proposed method

(a) Original (b) UCE (c) Proposed



(d) Original (e) UCE (f) Proposed

Figure 8: Original and enhanced images of "kodim04" using UCE and the proposed method

3.3 Embedding Capacity

The proposed method and UCE achieve contrast enhancement and data embedding by performing repeated histogram shifting. The more histogram shifting repetitions performed, the larger the embedding capacity, resulting in a linear relationship between the number of histogram shifting repetitions and the embedding capacity. Fig. 9 shows the embedding capacities of both UCE and the proposed method when applied at the same number of histogram shifting repetitions S .

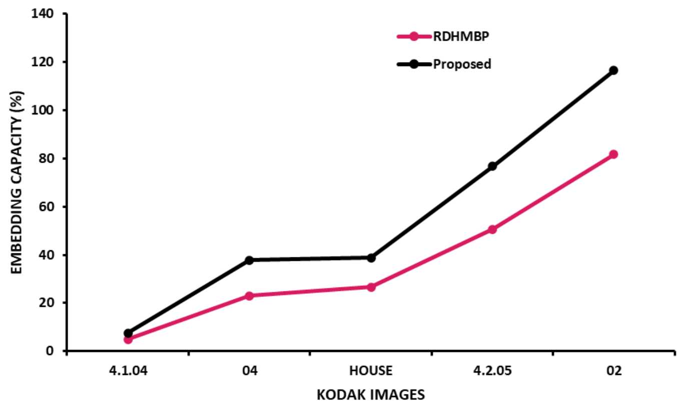


Figure 9: Comparison of embedding capacity of UCE and the proposed method

In Fig. 9, UCE and the proposed method achieve different embedding capacities when applied at the same histogram shifting repetition. Tabs. 3 and 4 show the numerical values of the embedding capacities and the embedding rates of UCE and the proposed method.

Table 3: Embedding rates of UCE and the proposed method for "kodim02", "kodim04", and "4.1.04"

Method	Image	S	Embedding capacity (bits)	Embedding rate (bpp)
	kodim02	15	817119	0.69
UCE	kodim04	15	229576	0.19
	4.1.04	19	49037	0.25
	kodim02	15	1164395	0.99
Proposed	kodim04	15	378410	0.32
	4.1.04	19	76251	3.91

Table 4: Embedding rates of UCE and the proposed method for "4.2.05", and "house"

Method	Image	S	Embedding capacity (bits)	Embedding rate (bpp)
UCE	4.2.05	29	505408	0.64
	house	27	266487	0.34
Proposed	4.2.05	29	767668	0.98
	house	27	388201	0.49

In enhancing and embedding data into images, the least maximum number of repetitions S is set as the parameter to determine the number of histograms shifting repetitions needed to be performed. At the same number of repetitions, S, it can be observed that the proposed method embeds larger bits whiles maintaining a better visual quality as compared to the UCE method. The proposed method, in all cases, achieves better visual quality and higher embedding capacity than the uniform contrast enhancement (UCE) method.

4 Conclusion

This paper proposes a contrast enhancement method for color images based on the RGB (red, green, and blue) color model. The proposed method performs an equalized number of histogram shifting repetitions among the RGB channels by applying a bi-histogram shifting contrast enhancement method on each RGB channel, then combines the channels to form the enhanced image. The proposed method selects the two highest bins and two lowest bins from the image histogram to perform an equalized bidirectional histogram shifting repetitions while embedding secret data into enhanced images. The two highest bins are used as embedding and splitting bins, while the lowest bins as combining bins. The proposed method applies right histogram shifting (RHS) and left histogram shifting (LHS) in each repetition to embed data and split the highest bins while shifting and combining the lowest bins with their neighbors. Compared to an existing contrast enhancement method for color images and evaluated with PSNR, SSIM, RCE, and RMBE as quality assessment metrics, the experimental results show the proposed method's enhanced images are visually and qualitatively superior with a more evenly distributed histogram. The proposed method achieves higher embedding capacities and embedding rates in all images, with an average increase in embedding capacity of 52.1%.

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