Near Hue-Preserving Reversible Contrast and Saturation Enhancement Using Histogram Shifting

Rio KUROKAWA¹(a), Nonmember, Kazuki YAMATO¹, and Madoka HASEGAWA¹, Members

SUMMARY In recent years, several reversible contrast-enhancement methods for color images using digital watermarking have been proposed. These methods can restore an original image from a contrast-enhanced image, in which the information required to recover the original image is embedded with other payloads. In these methods, the hue component after enhancement is similar to that of the original image. However, the saturation of the image after enhancement is significantly lower than that of the original image, and the obtained image exhibits a pale color tone. Herein, we propose a method for enhancing the contrast and saturation of color images and nearly preserving the hue component in a reversible manner. Our method integrates red, green, and blue histograms and preserves the median value of the integrated components. Consequently, the contrast and saturation improved, whereas the subjective image quality improved. In addition, we confirmed that the hue component of the enhanced image is similar to that of the original image. We also confirmed that the original image was perfectly restored from the enhanced image. Our method can contribute to the field of digital photography as a legal evidence. The required storage space for color images and issues pertaining to evidence management can be reduced considering our method enables the creation of color images before and after the enhancement of one image.

key words: watermarking, reversible, contrast, saturation, color image

1. Introduction

The Internet has become integral to the lives of many people, and opportunities to access digital content have increased. Currently, digital content can be easily processed, copied, and distributed. However, this has resulted in unauthorized content copying or editing, such as copyright infringement. To solve this problem, digital watermarking has been used [1]–[5], which embeds information in the digital content. This technology can be applied to various tasks, such as the detection of unauthorized copying or falsified content. In particular, reversible digital watermarking methods are applied in fields that require reversibility as legal evidence, such as medical images and digital images [6].

Owing to the popularization of digital content, image processing has been used extensively in various fields. Contrast enhancement is an image processing technique that improves the visibility of underexposed and low-dynamic-range images. In addition, saturation enhancement improves the visibility. For contrast and saturation enhancements of color images, it is desirable to preserve the hue components of the image before and after enhancement. This is because if the hue is not preserved, the color appears different in the enhanced image. In addition, there is an application field such as the field using of digital photography as a legal evidence in which the reversibility of the color image is desirable, and the guarantee of reversibility can reduce the storage space required for color images and the risk of evidence management failures. However, most existing enhancement methods cannot restore the original image from an enhanced image [7]–[11].

Hence, Kim et al., Guan et al., and Nishikawa et al. proposed reversible contrast-enhancement methods for color images where reversible data hiding is utilized [12]–[14]. The method proposed by Kim et al. caused color distortion in the enhanced image in some cases. In contrast, the method proposed by Guan et al. does not cause color distortion in the enhanced image. Guan et al.’s method enhances the contrast by shifting the red, green, and blue (RGB) histograms while considering the hue component of the hue, saturation, and value (HSV) color space. The method converts the RGB component into min, median, and max channels, and embeds information bits in the max channel by shifting less significant histogram bins and dividing the two most significant bins based on the information bits. In addition, processing is performed to save hue components. Consequently, the histogram of the embedded component is nearly equalized, and the contrast of the original image is enhanced. The enhanced image obtained using this method retains the hue component. However, the saturation component of the enhanced image was lower than that of the original image, and the obtained image exhibited a pale color tone. In addition, while maintaining the hue component of the HSV color space, it is difficult to reversibly enhance the saturation because the enhanced pixel values are not integer but real numbers, and it is required to embed the decimal part after enhancement. This post-processing to embed the decimal part causes degradation in the enhanced image. Furthermore, the pure payload is low because a reversible embedding process is performed for only one component.

In contrast, Nishikawa et al.’s method enhances the contrast and saturation naturally, although it cannot preserve the hue component. In addition, the pure payload is high because it uses three components for embedding.

Herein, we propose a reversible contrast and saturation enhancement method for color images that nearly preserves the hue component by preserving the median value of the stacked histogram that integrates the RGB component. In
the proposed method, the enhanced pixel values are integer values because they do not consider the relationship between RGB and HSV color spaces. As a result, the proposed method can avoid image degradation due to additional embedding after enhancement. The remainder of this paper is organized as follows: The method proposed by Nishikawa et al. is described in Sect. 2. Section 3 presents the proposed method. The experimental results are provided in Sect. 4. In Sect. 5, we present our conclusions.

2. Nishikawa et al.’s Method

The method proposed by Nishikawa et al. [14] enhances the contrast and saturation of a color image while preserving the difference between the median values of each color component. Figure 1 shows a flow diagram of Nishikawa et al.’s method. As shown in Fig. 1, preprocessing was performed first, after which embedding and enhancement processes based on Wu’s method [15] were performed to embed the location map (LM), side information, and other additional payloads. LM indicates the location at which the pixel level is changed by preprocessing.

2.1 Preprocessing

During preprocessing, empty bins are generated at both ends of the RGB histograms to avoid overflow and underflow of the brightness value owing to the process explained in Sect. 2.2.

First, steps 1–3 were applied separately for each color component.

**Step 1:** The sum of the frequencies of two adjacent bins in the histogram of a color component is calculated using Eq. (1).

\[ S_{hist}(i) = h(i) + h(i + 1), \]

\[ 0 \leq i \leq 254, \]

where \( i \) is the brightness value, and \( h(i) \) returns the number of pixels with a value \( i \) in the current color component.

**Step 2:** Two bins that yield the two lowest \( S_{hist}(i) \) were selected, and they were set as \( P_{small} \) and \( P_{large} \), where \( P_{small} < P_{large} \). Bins \( P_{small} \) and \( P_{large} \) were merged with \( P_{small} + 1 \) and \( P_{large} + 1 \), respectively, by subtracting 1 from all pixels of \( P_{small} + 1 \) and \( P_{large} + 1 \), respectively. Consequently, bins \( P_{small} + 1 \) and \( P_{large} + 1 \) become empty bins.

Additionally, we generated a binary LM that indicated the location at which the pixel level was changed by preprocessing. The LM, \( P_{small} \) and \( P_{large} \) were embedded in a later process and utilized to recover the original image during restoration. The LM was generated using Eq. (2).

\[ b_k = \begin{cases} 
1 & \text{if } i = P_{small} \\
0 & \text{if } i = P_{small} + 1 \\
0 & \text{if } i = P_{large} \\
1 & \text{if } i = P_{large} + 1 
\end{cases}, \]

where \( b_k \in \{0, 1\} \) is the \( k \)-th bit value of the LM.

**Step 3:** The histogram was shifted to move bins from the 0 and 255 sides to the middle part of the histogram using Eq. (3).

\[ i' = \begin{cases} 
i + 1 & \text{if } i \leq P_{small} \\
i & \text{if } P_{small} < i \leq P_{large} \\
i - 1 & \text{if } P_{large} < i 
\end{cases}. \]

where \( i' \) and \( i \) represent the brightness values of the preprocessed and original images, respectively. An example of the preprocessing is shown in Fig. 2. The two red bins in Fig. 2 show \( P_{small} \) and \( P_{large} \), respectively. Two blue bins in Fig. 2 show \( P_{small} + 1 \) and \( P_{large} + 1 \), respectively. The green bins show the shifted bins in Eq. (3).

These steps were repeated \( N \) times to generate \( 2N \) empty bins in total on the 0 and 255 sides of the histogram. In addition, these steps were performed for each color component. Let \( L_x \) and \( R_x \) be the number of empty bins on the 0 side (left side) and 255 side (right side) of the histogram of color \( x \in \{R, G, B\} \), respectively. \( L_x + R_x = 2N \) and \( L_x = R_x = N \) for all colors when step 3 is completed. \( N \) was arbitrarily determined by the user, and the maximum value of \( N \) depended on the image used.

**Step 4:** After the above steps are applied to each color component, we shift each histogram by adding (or subtracting) the same value to (or from) each pixel such that the medians of each component were equal to those of the original image. For example, assume that the original medians of \( R \),

![Flow diagram of Nishikawa’s method.](image1)

![Example of the preprocessing.](image2)
G, and B are 100, 120, and 180, respectively. If the preprocessed median values are 101, 119, and 178, then −1, 1, and 2 are added to each color component, respectively.

**Step 5:** Each histogram was further shifted by the same amount to shift the second-largest median value to 127. For example, if the medians of R, G, and B are 100, 120, and 180, respectively, then 7 is added to all components such that the medians become 107, 127, and 187, respectively. This shift was introduced to enhance the contrast, even when the original image was over- or under-exposed. If the pixel value becomes less than 0 or more than 255 via these shifting processes, then the amount of shifting is adjusted to fit the pixel level range. As a result, \( L_x \neq R_x \) but still \( L_x + R_x = 2N \).

To restore the original image, the number of empty bins on the 0 and 255 sides for each RGB component \( (L_x, R_x) \), \( x \in \{R, G, B\} \) were embedded as the side information in the subsequent process described in Sect. 2.2. The added values to shift the histograms in the process above can be obtained using this information. Figure 3 shows an example of a histogram transition using these processes. The white bins in Fig. 3 show the median value of each color component, and \( M_x (x \in \{R, G, B\}) \) represents the median of each color in the original image.

### 2.2 Embedding and Enhancement Processes

In Nishikawa et al.’s method, the embedding and enhancement processes based on Wu’s method [15] were utilized to embed the LM, side information for restoring the original image, and other additional payloads. The embedding process described below was applied separately to each color component.

The embedding process is similar to Wu’s method; however, Nishikawa et al.’s method separates the process into the following three cases based on the selection method of the two bins (pixel values) used for embedding. Case (a) is the same as that of Wu’s method.

(a) One bin is greater than the median, and the other is less.
(b) Both bins are greater than the median.
(c) Both bins are less than the median.

These constraints enable the difference between the medians of the two colors to be maintained, for example, between R and G, before and after embedding.

\( L_x \) and \( R_x \), \( x \in \{R, G, B\} \) are the number of empty bins on the 0 and 255 sides of the histogram of the color component, respectively. \( N \) is the number of shifts, as explained in the previous section, and \( 2N = L_x + R_x \) initially.

The LM of the current color component was embedded based on the following procedures: First, case (a) was selected, and each bit of the LM was embedded by dividing the two most frequent bins based on the embedding bit after creating empty bins next to the frequent bins by shifting the outer bins outside. The two most frequent bins were repeatedly searched and divided until no empty bins existed on either the 0 or 255 side. \( L_x \) and \( R_x \) were updated based on the shifted histogram. Subsequently, if the number of empty bins on the zero side is zero \( (L_x = 0) \), then case (b) is selected. However, if the number on the 255 side is zero \( (R_x = 0) \), then case (c) is selected.

In the following, we describe case (c) as an example. This is because case (a) is the same as Wu’s method, and case (b) can be realized by changing the order of the equation used in case (c), replacing the subtraction of case (c) with addition and reversing the direction of the inequality sign. First, we derive the histogram of the current color component, and the two most frequent bins \( I_{\text{small}} \) and \( I_{\text{large}} \)
(I_{small} < I_{large}) less than the median were selected. Here, I_{small} is the bin in which the pixel level is the smaller of the two, and I_{large} is that of the larger one. Subsequently, based on Eqs. (4) and (5), the other bins less than the median are shifted, and the two selected bins are divided based on the embedding bit.

\[
\begin{align*}
    i'' &= \begin{cases} 
        i' - 1 & \text{if } i' < I_{small} \\
        i' - b_k & \text{if } i' = I_{small}, \\
        i' & \text{if } i' > I_{small}
    \end{cases} \\
    i'' &= \begin{cases} 
        i' - 1 & \text{if } i' < I_{large} \\
        i' - b_k & \text{if } i' = I_{large}, \\
        i' & \text{if } i' > I_{large}
    \end{cases}
\end{align*}
\]

where \( i' \) is the pixel value of the image after preprocessing, \( i'' \) the pixel value after embedding, and \( b_k \) is the \( k \)-th bit value (0 or 1) of the watermark information. The watermark information is a binary bit sequence obtained by concatenating the LM and side information. If the number of bits of \( b_k \) is smaller than the number of pixels of \( I_{small} \) or \( I_{large} \), the bin is not completely divided. Therefore, similar to Wu’s method, a random bit sequence is connected after the watermark information. The random bit sequence can be replaced by a payload, such as copyright information.

An example of embedding in case (c) is shown in Fig. 4. The white bin in Fig. 4 shows the median value. The blue and red bins represent \( I_{small} \) and \( I_{large} \), respectively.

This process was repeated \( N \) times for each color component. Consequently, the histogram spreads out, and the contrast is enhanced. It is noteworthy that this method significantly changed the hue.

In Nishikawa et al.’s method, the contrast can be enhanced because histogram equalization is performed artificially in each color component. However, the saturation cannot always be enhanced because the histogram of each color component may be equalized only in a certain direction (0 or 255 side direction) because of some cases in step 5 of the preprocessing.

3. Proposed Method

To preserve hue, all pixels must satisfy the relationship shown in Eq. (6) in the images before and after the enhancement [16].

\[
\begin{align*}
    \left( \frac{R'(x, y)}{R(x, y)} \right) - \left( \frac{G'(x, y)}{G(x, y)} \right) - \left( \frac{B'(x, y)}{B(x, y)} \right) &= n \\
    \left( \frac{R'(x, y)}{R(x, y)} \right) - \left( \frac{G'(x, y)}{G(x, y)} \right) - \left( \frac{B'(x, y)}{B(x, y)} \right) &= m
\end{align*}
\]

where \((R(x, y), G(x, y), B(x, y))\) and \((R'(x, y), G'(x, y), B'(x, y))\) are the pixel values of the image before and after enhancement at the pixel position \((x, y)\), respectively. \( n \) and \( m \) are the scaling and shifting parameters, respectively.

The preprocess aims to create empty bins on the 0 and 255 sides. In Nishikawa et al.’s method, if \( P_{small} \) and \( P_{large} \) are far apart, the number of bins outside the range between \( P_{small} \) and \( P_{large} \) is small. On the contrary, if bins \( P_{small} \) and \( P_{large} \) are close to each other, as shown in Fig. 2, most bins are outside the range between \( P_{small} \) and \( P_{large} \). As a result, most bins are shifted to the inner side of the histogram by the preprocess and are affected by the shift. In addition, if the medians of each color channel in an image differ significantly from each other and should be preserved, then most bins of the histogram of a specific color component will shift only in a certain direction (plus or minus direction) in the embedding and enhancement processes. Furthermore, the two most frequent bins of each RGB component were selected using the same process. Consequently, the number of pixels that cannot maintain the relation shown in Eq. (6) is increased, and an enhanced image that does not preserve the hue component of the original image is generated. For example, if the histograms of the red and green components shift only in the positive and negative directions, respectively, then the shifting parameter \( m \) differs for each component. Consequently, the hue changes significantly, whereas contrast and saturation are enhanced.

In Guan’s method, the shifting parameter \( m \) is selected to preserve the hue component, then the contrast is enhanced, whereas the saturation after enhancement is lower than that of the original image.

In this section, we explain the proposed method for solving these problems. Our method enhances the contrast and saturation of color images and preserves the hue component better than Nishikawa’s method. In our method, we used a stacked histogram of all color components for the enhancement. The color of the enhanced image is more natural because fewer bins are shifted by our method, and the bins of all color components shift in one direction by maintaining the median of the stacked histogram before and after the image. The flow diagram of the proposed method is the same as that of Nishikawa’s method, as shown in Fig. 1. However, the processing details were different. In particular, some constraints were added to avoid changing the median of the stacked histogram.
3.1 Preprocessing

During preprocessing, empty bins were generated at both ends of the RGB histograms to avoid overflow and underflow of the brightness value, as explained in Sect. 3.2.

Step 1: A stacked histogram was created by adding the frequency of the brightness values of the RGB components, as shown in Fig. 5. The median bin of the stacked histogram \( I_{\text{med}} \) was maintained during subsequent processing.

Step 2: The sum of the frequencies of two adjacent bins in the stacked histogram is calculated using Eq. (1). In our method, \( i \) is replaced with \( i_S \), where \( i_S \) is the index of the bin of the stacked histogram and \( h(i_S) \) returns the frequency of \( i_S \) in the stacked histogram.

Step 3: The bin that yielded the lowest \( S_{\text{hist}}(i_S) \) was selected, and \( i_S \) was set as \( P \). If \( I_{\text{med}} > P \), then bin \( P \) is merged with bin \( P + 1 \) in step 4. If \( I_{\text{med}} \leq P \), then bin \( P + 1 \) is merged with bin \( P \).

Step 4: The stacked histogram was shifted to create an empty bin on the 0 or 255 side of the histogram using Eq. (7) or Eq. (8). If \( I_{\text{med}} > P \), then Eq. (7) is used. In contrast, if \( I_{\text{med}} \leq P \), then Eq. (8) is used.

\[
i' = \begin{cases} 
i + 1 & \text{if } i \leq P \\ 
i & \text{if } i > P \end{cases}
\]  

\[
i'' = \begin{cases} 
i - 1 & \text{if } P < i \\ 
i & \text{if } i \leq P \end{cases}
\]  

where \( i' \) and \( i'' \) are the brightness values of the preprocessed and original images, respectively. When \( I_{\text{med}} > P \), a brightness value lower than \( P \) was added to 1 to merge \( P \) with \( P + 1 \), and an empty bin was generated on the 0 side. When \( I_{\text{med}} \leq P \), a brightness value greater than \( P \) was subtracted by 1 to merge \( P \) with \( P + 1 \), and the greater bins were shifted, and an empty bin was generated on the 255 side. Figure 6 shows an example of a histogram change when \( I_{\text{med}} > P \).

Step 5: This process was performed together with step 4. The image was raster scanned, and information regarding the changes performed to the pixels during preprocessing was recorded to guarantee reversibility. An LM with a modified brightness value is created based on Eq. (9).

\[
b_k = \begin{cases} 
1 & \text{if } i = P \text{ and } I_{\text{med}} > P \\
0 & \text{if } i = P + 1 \text{ and } I_{\text{med}} > P \\
0 & \text{if } i = P \text{ and } I_{\text{med}} \leq P \\
1 & \text{if } i = P + 1 \text{ and } I_{\text{med}} \leq P 
\end{cases}
\]  

(9)

where \( b_k \in \{0, 1\} \) is the \( k \)-th bit of the LM.

These steps were repeated \( N \times 2 \) (\( N \): the number of shifts). Finally, for an image with \( 2N \) empty bins on the 0 and 255 sides of the histogram, each RGB component was generated.

3.2 Embedding and Enhancement Processes

In the embedding and enhancement processes, the LM and side information are embedded in the former and latter processes, respectively. The LM, side information and additional bits are embedded reversibly by shifting and splitting bin of the stacked histogram a total of \( 2N \) times.

3.2.1 Embedding of LM

In this process, the LM and additional payload are embedded, whereas \( I_{\text{med}} \) is maintained.

First, we searched for the most frequent bin \( I_{\text{max}} \) in the stacked histogram. If empty bins on 0 side did not exist, \( I_{\text{max}} \) was searched from values greater than \( I_{\text{med}} \). In contrast, if empty bins on 255 side did not exist, \( I_{\text{max}} \) was searched...
from values less than Imed. Subsequently, the information of the LM is embedded in Imax using Eqs. (10) and (11), respectively: When Imed > Imax, Eq. (10) is used to embed the information and shift the stacked histogram. Meanwhile, when Imed < Imax, Eq. (11) is used.

\[
i' = \begin{cases} 
-1 & \text{if } i' < I_{\text{max}} \\
0 & \text{if } i' = I_{\text{max}} \\
1 & \text{if } i' > I_{\text{max}} 
\end{cases} 
\]

(10)

\[
i'' = \begin{cases} 
-1 & \text{if } i' < I_{\text{max}} \\
i' + b_k & \text{if } i' = I_{\text{max}} \\
i' & \text{if } i' > I_{\text{max}} 
\end{cases} 
\]

(11)

where \(i''\) is the brightness value of the enhanced and embedded images, and \(b_k \in \{0, 1\}\) is the \(k\)-th bit of the LM. If the number of bits of \(b_k\) is smaller than the number of pixels of Imax, the bin is not completely divided. Therefore, similar to Wu’s method, a random bit sequence is connected after the LM. The random bit sequence can be replaced by a payload, such as copyright information. Figure 7 shows an example of this process.

There are two reasons for using a stacked histogram and Imax in the embedding process of the proposed method.

(i) The stacked histogram can reduce the amount of side information required to express the bin that is used in the embedding process to one-third. If the maximum bins are selected for each color component, such as Nishikawa et al.’s method, information about the three bins is required to restore the original image. In contrast, if the stacked histogram is used, only one piece of information about bin Imax is required.

(ii) Under the condition that the stacked histogram is used, Imax gives the maximum payload because the occurrence frequency is the highest among the stacked histogram bins.

By repeating this process \(2(N-1)\) times, each histogram is flattened, and the emphasized image is obtained.

The bit length of the LM was embedded at the end of the embedding process described in Sect. 3.2.2 as side information.

3.2.2 Embedding of Side Information

In our method, the side information is embedded to restore the original image. Table 1 lists the details of side information.

As described in Sect. 3.2.1, the \(2(N-1)\) split bins out of \(2N\) split bins were used for embedding the LM and additional bits. The side information was embedded in the last two split bins, that is, the \(2N - 1\)-th and \(2N\)-th split bins. During embedding, we first selected the most frequent bin Imax from the stacked histogram with considering Imed and the number of empty bins on 0 and 255 side. Subsequently, using Eq. (10) or (11), the histogram is shifted, and the side information is embedded. It is noteworthy that 16 pixels in the upper left of the image were excluded when creating the histogram in this process to guarantee reversibility. The least significant bits (LSBs) of the upper left 16 pixels were used in the final step.

Finally, the two Imax values used at the \(2N - 1\)-th and \(2N\)-th shifts were embedded into the LSBs of the upper left 16 pixels of the color component. In our experiment, the R component was used for this purpose.

3.3 Restoration Process

The original image can be completely restored from the enhanced image by performing the embedding process in reverse order. Figure 8 shows a flow diagram of the restoration process. As shown in Fig. 8, extraction and restoration processes are performed to extract side information, LM, and other additional payloads and restore the preprocessed image. Subsequently, post-processing is performed to restore
the original image using the extracted side information and the LM. In this process, the reverse process of preprocessing is performed, as described in Sect. 3.1 is performed.

3.3.1 Extraction and Restoration Processes

In the extraction and restoration processes, the side information and LM are extracted in the former and latter processes, respectively. In addition, the image after preprocessing was restored.

3.3.1.1 Extraction of Side Information

In this process, the side information is extracted, whereas \( I_{\text{med}} \) is maintained.

First, the \( I_{\text{max}} \) at the \( 2N - 1 \)-th and \( 2N \)-th shifts are extracted from the LSBs of 16 pixels at the upper left of the R component of the enhanced image to obtain the side information from the enhanced image. Subsequently, the extraction of the side information and the histogram shift in the reverse direction were performed using the extracted \( I_{\text{max}} \) and Eqs. (12) and (13), respectively.

\[
b_k^* = \begin{cases} 1 & \text{if } i' = I_{\text{max}} - 1 \text{ and } I_{\text{med}} > I_{\text{max}} \\ 0 & \text{if } i' = I_{\text{max}} \text{ and } I_{\text{med}} > I_{\text{max}} \\ 1 & \text{if } i'' = I_{\text{max}} + 1 \text{ and } I_{\text{med}} < I_{\text{max}} \\ 0 & \text{if } i'' = I_{\text{max}} \text{ and } I_{\text{med}} < I_{\text{max}} \end{cases} \quad (12)
\]

\[
i' = \begin{cases} i'' + 1 & \text{if } i'' < I_{\text{max}} \text{ and } I_{\text{med}} > I_{\text{max}} \\ i'' & \text{if } i'' \geq I_{\text{max}} \text{ and } I_{\text{med}} > I_{\text{max}} \\ i'' - 1 & \text{if } i'' > I_{\text{max}} \text{ and } I_{\text{med}} < I_{\text{max}} \\ i'' & \text{if } i'' \leq I_{\text{max}} \text{ and } I_{\text{med}} < I_{\text{max}} \end{cases} \quad (13)
\]

where \( b_k^* \in \{0, 1\} \) is the \( k \)-th bit value of the extracted information, \( i' \) is the restored brightness value of the preprocessed image, and \( i'' \) the brightness value of the enhanced image. However, 16 pixels in the upper left were excluded from this process. The \( I_{\text{max}} \) used for the \( 2N \)-th shift is used first because this process is performed twice.

The side information is obtained by extracting the specified number of bits from the extracted bit string in order, beginning from the first bit. In addition, the image after the embedded LM was restored by placing the extracted LSBs of 16 pixels of the R component in the upper left of the original location.

3.3.1.2 Extraction of LM

In this process, the LM and additional payload are extracted, whereas \( I_{\text{med}} \) is maintained.

The extraction of the LM requires \( I_{\text{max}} \) from the side information. Therefore, LM extraction and image restoration are performed after preprocessing using the extracted side information \( I_{\text{max}} \) and Eqs. (12) and (13) for \( 2(N - 1) \) times. Consequently, the image obtained after preprocessing was restored.

3.3.2 Post-Processing

In the final process, the original image is restored using the extracted side information and LM. First, bit strings pertaining to the “LM size” are extracted from the extracted bit string, and the LM is obtained. Subsequently, the original image was restored using LM, \( P \), and Eq. (14).

\[
i = \begin{cases} i' - 1 & \text{if } i' \leq P \text{ and } I_{\text{med}} > P \\ i' - b_k' & \text{if } i' = P + 1 \text{ and } I_{\text{med}} > P \\ i' + 1 & \text{if } i' > P \text{ and } I_{\text{med}} \leq P \\ i' + b_k' & \text{if } i' = P \text{ and } I_{\text{med}} \leq P \end{cases} \quad (14)
\]

where \( i \) is the restored brightness value of the original image, and \( b_k' \in \{0, 1\} \) is the \( k \)-th bit value of the LM. When \( P < I_{\text{med}} \), brightness values less than \( P \) were decremented by \(-1\). In addition, if the brightness value is \( P + 1 \), then the brightness value is subtracted by \( b_k' \). On the other hand, when \( P \geq I_{\text{med}} \), brightness values exceeding \( P \) were incremented by \(+1\). In addition, if the brightness values are \( P \), then the brightness value is added by \( b_k' \).

The original image can be restored by repeating this process the same number of times as the “number of shifts.”

4. Experimental Results

In the experiment, we used 24 color images comprising 768 × 512 or 512 × 768 pixels from the Kodak Lossless True Color Image Suite [17]. Furthermore, a random binary bit sequence, whose occurrence probability of 0 was 0.5, was concatenated after LM when the embedding bits were insufficient. The number of shifts \( N \) was varied from 10 to 40 in increments of 10 to match the experimental condition of the compared method. In this section, we compare our method with Guan [13] and Nishikawa’s methods [14].

Three evaluation indices, that is, the hue similarity, relative contrast error (RCE) [18], and average and standard deviation of saturation, were used to evaluate the effect of color enhancement. Payloads were used to evaluate the capacity of the enhanced images.

The hue similarity was derived by comparing the hue histogram of the original image with that of the enhanced image. The hue component was obtained by converting the RGB component into an HSV component, because the preservation formula of the hue component (Eq. (6)) is the same as the conversion formula for the hue component in the HSV color space. This value was calculated using the OpenCV3 function “cv2.compareHist,” which returns the correlation between two histograms in the range \([-1, 1]\), where 1 is a perfect match.

The RCE indicates the degree of contrast enhancement. It is calculated as follows:

\[
\text{RCE} = \frac{\sigma_{\text{new}} - \sigma_{\text{original}}}{255} + 0.5,
\]

where \( \sigma_{\text{new}} \) and \( \sigma_{\text{original}} \) represent the standard deviations of the components of the enhanced and original images, respectively. We converted each RGB image into the CIE L*a*b* color space and used the L* component for this comparison. An RCE value greater than 0.5 indicates that the contrast of the enhanced image is more significant than.
that of the original image.

The average and standard deviation of the saturation were used to evaluate the degree of saturation enhancement. The saturation $C^*$ was calculated for each pixel in the image based on $C^* = \sqrt{a^*^2 + b^*^2}$, where $a^*$ and $b^*$ are the color channels of CIE $L^*a^*b^*$, and its average $A$ and standard deviation $\sigma$ for the image were used for evaluation. To determine the relative changes, the difference in the average saturation was calculated as follows:

$$D_{\text{ave}} = A_{\text{enh}} - A_{\text{org}}, \quad (16)$$

where $A_{\text{enh}}$ is the average saturation of the enhanced image, and $A_{\text{org}}$ is that of the original image. Similarly, the difference in the standard deviation was calculated as follows:

$$D_{\text{s.d.}} = \sigma_{\text{enh}} - \sigma_{\text{org}}, \quad (17)$$

where $\sigma_{\text{enh}}$ is the standard deviation of the enhanced image and $\sigma_{\text{org}}$ is the standard deviation of the original image. $D_{\text{ave}}$ and $D_{\text{s.d.}}$ values greater than 0 indicate that the saturation of the enhanced image is more significant than that of the original image. CIE $L^*a^*b^*$ can evaluate the difference in color close to the color perception of the human eye. Therefore, instead of using the saturation component of the HSV color space, we use the uniform color space CIE $L^*a^*b^*$.

The pure payload capacity (PL) indicates the amount of information that can be embedded. The PL was calculated as follows:

$$\text{PL} = \frac{\text{length}(b_k)}{w \times h \times c} \quad \text{[bpp]}, \quad (18)$$

where $b_k$ is the bit stream of the watermark information, excluding the information necessary to restore the original image. Therefore, the LM and side information presented in Table 1 are not included. In Eq. (18), length($) is a function that returns the length of a bit stream, $w$, $h$, and $c$ are the width, height, and number of channels of the image, respectively.

Figure 9 shows four original images and their enhanced images with $N = 40$. Figures 9 (a), (e), (i), and (m) show the original images of Kodim03, Kodim04, Kodim05, and Kodim24, respectively. Figures 9 (b), (f), (j), and (n) show the enhanced images of Guan’s method. Figures 9 (c), (g), (k), and (o) show the enhanced images of Nishikawa’s method. Figures 9 (d), (h), (l), and (p) show the enhanced images of the proposed method. As shown in Figs. 9 (b), (f),
(j), and (n), the color from Guan’s method is pale, whereas the hue is similar to that of the original image. As shown in Figs. 9(c), (g), (k), and (o), Nishikawa’s method can enhance the saturation better than Guan’s method. However, in Nishikawa’s method, the hue of the enhanced image differed from that of the original image at time, as shown in Fig. 9(g). Figure 9(g) shows the color of a woman’s skin becoming blue. This result is associated with the maintenance of the median of each color component and the shift of bins in only a certain direction. By contrast, the proposed method enhanced the color of the image while maintaining the color of the original image, and the enhanced image became colorful.

Four images were evaluated in terms of the objective evaluation indices. Table 2 lists the hue similarities. As shown in the table, the hue similarity of the proposed method was less than that of Guan’s method, but significantly better than that of Nishikawa’s method.

As presented in Table 3, the three methods can enhance the contrast of color images because the RCE exceeded 0.5, in all images. Although the proposed method indicated a smaller RCE than the two conventional methods for Kodim04, the contrast can be enhanced, which is equivalent to the conventional methods.

As shown in Tables 4 and 5, the differences in the average and standard deviation of the saturation of Guan’s method were negative. This implies that the saturation decreased by Guan’s method, whereas the hue was preserved before and after the enhancement. Consequently, the color of the enhanced image obtained using Guan’s method was paler than that of the original image. Meanwhile, because the proposed method indicates positive values, saturation can be emphasized. Consequently, the enhanced image is more colorful.

Table 6 shows that the proposed method yielded an improved payload compared with Guan’s method. This is because Guan’s method embeds the information in one channel, whereas the proposed method embeds it in three channels. In Nishikawa’s method, the number of payloads is higher than that in the proposed method. This is because Nishikawa’s method selects the most frequent bins for each color component to embed the information.

Next, Kodak’s 24 images were evaluated using the objective metrics. Tables 7 through 12 show the mean and standard deviation of the 24 images (mean ± standard deviation). Table 7 shows the degree of hue similarity at each shift in the 24 Kodak images. The degree of hue similarity decreased as the number of shifts increased in...
Nishikawa’s method and the proposed method. In addition, in the proposed method, the hue was preserved more than Nishikawa’s method for all $N$, whereas the hue similarity value of Guan’s method was higher than that of the proposed method. Moreover, in the proposed method, the hue similarity value was higher than 0.8, for $N = 40$. This result is associated with the maintenance of the median value of the stacked component and the shifting of bins in the plus and minus directions during the embedding and enhancement processes.

Table 8 shows the RCE for each shift in the 24 Kodak images. The RCE values of all methods increased with the number of shifts, and the contrast was enhanced because the RCE value exceeded 0.5, for all numbers of shifts. Moreover, because the RCE values of all methods were similar, it implied that the proposed method enhanced the contrast equivalently to the two conventional methods.

Tables 9 and 10 show the mean and standard deviation of $D_{ue}$ and $D_{cd}$, respectively, for the 24 images. In Guan’s method, as the number of shifts increased, the average saturation became negative, indicating that the saturation decreased compared with that of the original image. This is because contrast enhancement was applied while the hue component was preserved. Meanwhile, in the proposed method, as the number of shifts increased, both the average saturation and standard deviation increased, implying that saturation enhancement was possible. This is because histogram shift and information embedding were performed without significantly changing the hue during the embedding process. In contrast, the saturation in Nishikawa’s method decreased because the value was negative.

Table 11 shows the payload at each shift in the 24 Kodak images. The payload increased in proportion to the number of shifts when using Guan’s method and the proposed method. The proposed method contained 1.4–2 times more payload than Guan’s method. Although Nishikawa’s payload was the largest among the three methods, the hue changed significantly. In Nishikawa’s method, the most frequent bins $R_{max}$, $G_{max}$, $B_{max}$ in RGB components were used to embed the LM, side information, and extra information. Generally, $R_{max} \neq G_{max} \neq B_{max}$ for typical natural images.

In contrast, $I_{max}$ in the stacked histogram was used in our method. The frequency of bin $I_{max}$ is given as follows:

$$h(I_{max}) = h(R_{I_{max}}) + h(G_{I_{max}}) + h(B_{I_{max}})$$  \hspace{1cm} (19)

Here, $h(i)$ is the frequency of bin $i$. In addition, the following relationship exists:

$$h(R_{I_{max}}) \leq h(R_{max}), \quad h(G_{I_{max}}) \leq h(G_{max}), \quad h(B_{I_{max}}) \leq h(B_{max})$$  \hspace{1cm} (20)

Therefore,

$$h(I_{max}) \leq h(R_{max}) + h(G_{max}) + h(B_{max})$$  \hspace{1cm} (21)

For this reason, the payload of the proposed method is smaller than that of the conventional method, although the side information is reduced.

In summary, the proposed method preserved hues better than Nishikawa’s method and enhanced saturation better than Guan’s and Nishikawa’s methods. The contrast emphasized using the proposed method by preserving the median value of the stacked histogram was comparable to that of Guan’s and Nishikawa’s methods. In addition, the proposed method enabled the payload to be increased compared to Guan’s method.

5. Conclusion

We proposed a method to improve the contrast and saturation of an image while nearly maintaining the hue of the original image. In color image enhancement, it is possible to maintain the color balance if the contrast and saturation of the color image is enhanced while preserving the hue component. Therefore, the color balance can be maintained in the proposed method because as it can solve the problem of the Nishikawa et al.’s method not being able to preserve the hue component, and the hue component can be almost preserved while enhancing the contrast and saturation. In addition, the original image can be completely restored from the enhanced image. Furthermore, the payload can be increased compared with that of Guan et al.’s method.

Our method can contribute to the field of digital photography as a legal evidence. Our method enables color images to be created before and after highlighting from a single image, thereby reducing the storage space required for color images and the risk of evidence management failure.

In the future, we will consider a reversible contrast and saturation enhancement method that completely retains the hue of the original image even after enhancement. Although the method proposed herein can reduce the change in the color balance of the original image, it does not perfectly preserve the hue of the original image. Finally, we will attempt to increase payload capacity in future studies.

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**Rio Kurokawa** received a B.E. degree from Utsunomiya University, Tochigi, Japan, in 2020. He is currently an M.E. student at the Graduate School of Regional Development and Creativity, Utsunomiya University. His current research interests include image processing and reversible digital watermarking.

**Kazuki Yamato** is a research associate at Utsunomiya University from April 2020. His research interests include data hiding, image processing, audio signal processing, and application of tunable focus lens. He received the B.E., M.E., and Ph.D. degrees from Utsunomiya University, Tochigi, Japan, in 2009, 2011, and 2014, respectively. He is a member of the IEICE, IPSJ, JAMIT, and IEEE.

**Madoka Hasegawa** is a professor at the School of Engineering, Utsunomiya University. Her current research interests include image coding, image processing, digital watermarks, and graphical passwords. She received the B.S., M.S., and Ph.D. degrees in engineering from Utsunomiya University in 1994, 1996, and 1999, respectively. She is a member of the IEICE, ITE, IIEJ, IPSJ, and IEEE.