Reversible Contrast Enhancement

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Abstract. This paper proposes a novel idea of reversible contrast enhancement (RCE) for digital images. Different from the traditional methods, we aim to embed the reversible feature into image contrast enhancement, making sure that the processed image can be losslessly turned back to the original. The original image is enhanced by histogram shrink and contrast stretching. Meanwhile, side information is generated and then embedded into the contrast enhanced image. On the other end, we extract side information from the processed image and reconstruct the original content without any error. Experimental results show that good contrast and good quality can be achieved in the RCE processed image.

Keywords: Reversible image processing · Reversible contrast enhancement · Reversible data hiding · Steganography

1 Introduction

Traditional image processing achieves a specified image by modifying the pixel values, e.g., image enhancement, denoising and restoration. Meanwhile, different assessment algorithms are developed to evaluate the processing capability, like the human visual effect, the minimal square errors, and so on. In the past few decades, a huge amount of methods have been proposed to promote the research field [1].

Nowadays, more and more images are used in social networks like Facebook, Twitter, Flickr, and so on. With many processing tools, people can prettify their contents before image uploading or storage. In this situation, one problem emerges. If one hopes to possess both the original and the processed images, he/she has to save two copies, which requires more storage overhead. To resolve this problem, we propose a novel idea of reversible image processing (RIP). As shown in Fig. 1, the processing method guarantees that the processed image can be reversibly processed to the original without any errors. Hence, the image owner only needs to save one copy of the image. To the best of our knowledge, few image processing works have been done in the field of RIP. One work might be semantic image compression [2]. An image is compressed to a visible one with smaller size, and the original can be decompressed with lossy or lossless quality. This work can be viewed as a generalized RIP.

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Fig. 1. Reversible image processing

The proposed idea of RIP is inspired by the works [3, 4]. Purpose of steganography works is to embed additional message into digital images [8, 9]. Alternatively, we change the aim from steganography to reversible image processing. In this paper, we provide a method of reversible contrast enhancement (RCE). To this end, we propose an algorithm based on state-of-the-art contrast enhancement method in [5] to indicate that RCE with good processing results can be achieved by combing image processing with data hiding [6]. We also believe that the proposed work would be of some help to the development of image processing, and more works like reversible image denoising and reversible image restoration can be developed in the future.

Framework of the proposed RCE method is shown in Fig. 2. We first enhance the original image by histogram shrink and global image enhancement, and then embed the generated side information into the processed image. On the recovery end, we extract side information from processed image and reconstruct the original content without any error. Experimental results show that the processed image with good contrast and quality can be achieved using the proposed method.

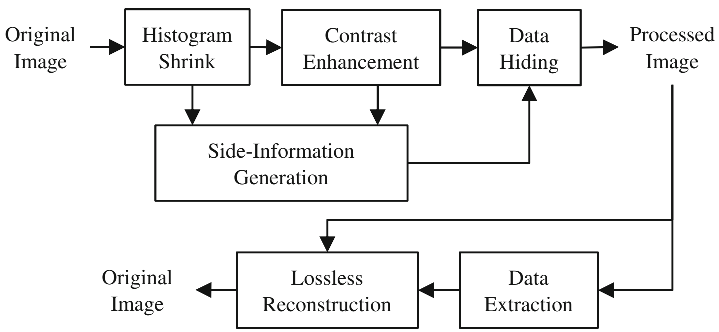

Fig. 2. Framework of reversible image processing

2 Proposed Method

2.1 Histogram Shrink

Given a digital image $\mathbf{X} = \{X(i,j)\,|X(i,j) \in [0, 255],\, i = 1, 2, \ldots, M, j = 1, 2, \ldots, N\}$ with $M \times N$ pixels, we first calculate its histogram as $\mathbf{h}_X = \{h_X(k)\,|k = 0, 1, \ldots, 255\}$, where $h_X(k) \in [0, \mathbb{Z}^+]$ is the number of occurrences of the gray-level k in $\mathbf{X}$. Let $\mathrm{A} = \{a_1, a_2, \ldots, a_K\}$ be the set of all possible gray-levels in $\mathbf{X}$, where $a_1 < a_2 < \ldots < a_k$, and K is the number of existing gray-levels.

We further choose a threshold T satisfying $1 \leq T \leq 128$. Let $S = 255–K$. If $S < T$, find $T–S$ gray-levels from $\mathcal{A}$. Initially we let $\mathcal{A}' = \mathcal{A}$ and $\mathcal{B} = \{\}$. Find the gray-level $a_i(i \in [1, K])$ that satisfies $h(a_i) = \min\{h_X(a_k)|a_k \in \mathrm{A}'\}$, and remove a_i from A'. If $a_i > 1$, $h(a_i–1) \neq 0$ and $a_i-1 \notin \mathrm{B}$, we add a_i to B, *i.e.*, $\mathrm{B} = \mathrm{B} + \{a_i\}$. Repeat the operation until there are $T–S$ elements in B. Assuming $\mathrm{B} = \{b_1, b_2, \ldots, b_{T-S}\}$, we modify the original image to construct a new image $\mathbf{X}'$ by

$$X^{'}(i,j) = \begin{cases} X(i,j) - 1, & \text{if } X(i,j) \in \mathrm{B} \\ X(i,j), & \text{otherwise} \end{cases} \tag{1}$$

where $i = 1, 2, \ldots, M,\ j = 1, 2, \ldots, N$. Meanwhile, generate a binary map $\mathbf{M}$ to record the modification by

$$M(i,j) = \begin{cases} 1, & \text{if } X(i,j) \in \mathrm{B} \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

If $S \geq T$, the binary map is not required and $\mathbf{X}' = \mathbf{X}$.

Thus, there are $J = max(255–K,\ T)$ zeros in the histogram $\mathbf{h}_{X'}$. Denote the gray-levels that does not exist in $\mathbf{X}'$ as a set $\mathrm{Z} = \{z_i|z_i \in [0, 255], i = 0, 1, \ldots, J-1\}$. Let $\{p_0, p_1, \ldots, p_{255-J-1}\}$ be the set of all gray-levels that exist in $\mathbf{X}'$, where $p_0 < p_1 < \ldots < p_{255-J-1}$. Next, we construct a new image $\mathbf{Y}$ by

$$Y(i,j) = k, \text{if } X^{'}(i,j) = p_k \tag{3}$$

where $k = 0, 1, \ldots, 255-J-1, i = 1, 2, \ldots, M$ and $j = 1, 2, \ldots, N$. This way, existing gray-levels in $\mathbf{X}'$ shrinks from $\{p_0, p_1, \ldots, p_{255-J-1}\}$ to $\{0, 1, \ldots, 255-J-1\}$.

2.2 Global Contrast Enhancement

Based on the global contrast enhancement method in [5], we propose a modified algorithm that is suitable for **RCE**. To enhance the contrast of image $\mathbf{Y}$, we first calculate the spatial entropy of the image. Divide the image $\mathbf{Y}$ into non-overlapped blocks, each of which contains $m \times n$ pixels. Thus, there are $[M/m]•[N/n]$ blocks, where [•] is the rounding operator. Next we generate the spatial histogram of gray-levels in each block by

$$\mathbf{H} = \{H_k(i,j)\,|\,k = 0, 1, \ldots, 255 - J - 1\}$$

where $H_k(i,j)$ is the number of occurrence of the gray-level k in the (i,j)-*th* block, $i = 1, 2, \ldots, [M/m]$ and $j = 1, 2, \ldots, [N/n]$. The size of each block can be identified by

$$m = \left[((255 - J)/(M/N))^{1/2}\right]$$

$$n = \left[((255 - J) \cdot (M/N))^{1/2}\right]$$

With the spatial histogram, the entropy measure for each level k is computed by

$$E(k) = \sum\nolimits_{i=1}^{[M/m]} \sum\nolimits_{j=1}^{[N/n]} H_k(i,j) log_2 H_k(i,j) \tag{4}$$

where $k = 0, 1, \ldots, 255 - J - 1$. Accordingly, the importance of each gray-level with respect to the other gray-levels is calculated using

$$f(k) = E(k) / \sum\nolimits_{l=0,k \neq l}^{255-J-1} E(l) \tag{5}$$

The measure $f(k)$ is further normalized using

$$f(k) \leftarrow f(k) / \sum\nolimits_{l=0}^{255-J-1} f(l) \tag{6}$$

Then, we find J gray-levels $\{k_1, k_2, \ldots, k_J\}$ $(k_1 < k_2 < \ldots < k_J)$ corresponding to J minimal $f(k)$ values. Accordingly, we construct a contrast-enhanced image $\mathbf{Z}$ by

$$Z(i,j) = \begin{cases} Y(i,j) + J, & \text{if } Y(i,j) > k_J \\ Y(i,j) + t - 1, & \text{if } Y(i,j) = k_t \\ Y(i,j) + t, & \text{if } k_t < Y(i,j) < k_{t+1} \\ Y(i,j), & \text{otherwise} \end{cases} \tag{7}$$

where $t = 1, 2, \ldots, J-1$, $i = 1, 2, \ldots, M$ and $j = 1, 2, \ldots, N$. After contrast enhancement, all existing gray-levels in $\mathbf{Z}$ is shifted to the range of [0, 255], and the gray-levels $\{k_1, k_2, \ldots, k_J\}$ are modified to $\{k_1, k_2 + 1, \ldots, k_i + i - 1, \ldots, k_J + J - 1\}$.

2.3 Data Hiding

During the procedure of contrast enhance, we have to record the side information including the set of gray-levels $\mathrm{Z} = \{z_i | z_i \in [0, 255], i = 0, 1, \ldots, J-1\}$ and the binary map $\mathbf{M}$. We record J gray-levels in Z using 8•(J + 1) bits containing an 8-bit header representing the number J. Meanwhile, we compress the binary map $\mathbf{M}$ to m_a bits using the *arithmetic encoding* algorithm. Next, the 8(J + 1) + m_a bits are embedded into the contrast-enhanced image $\mathbf{Z}$.

To accommodate the encoded bits, we select L gray-levels from $\{k_1, k_2 + 1, \ldots, k_i + i - 1, \ldots, k_J + J - 1\}$ that have the largest values of $f(i)(i = k_1, k_2, \ldots, k_J)$, such that

$$\sum\nolimits_{l=K_J+j-L}^{K_J+j-1} h_z(l) \geq 8L + 8(J+1) + m_a \tag{8}$$

where h_z is the histogram of image $\mathbf{Z}$ excluding eight pixels. Denote the selected gray-levels as $\{s_1, s_2, \ldots, s_L\}$ $(s_1 < s_2 < \ldots < s_L)$.

We hide the value s_L into the least significant bits (LSB) of the excluded eight pixels by bit replacement. Meanwhile, the values of $\{s_1, s_2, \ldots, s_{L-1}\}$ and LSBs of the excluded pixels are recorded. This way, we have $8L + 8(J + 1) + m_a$ bits to be embedded into **Z**. A marked image **W** can be generated by data hiding,

$$W(i,j) = \begin{cases} Z(i,j) + b_k, & \text{if } Z(i,j) \in S \\ Z(i,j), & \text{otherwise} \end{cases} \tag{9}$$

where $S = \{s_1, s_2, \ldots, s_L\}$, b_k is the *k-th* bit (0 or 1) to be hidden, $k = 1, 2, \ldots, 8L + 8(J+1) + m_a, i = 1, 2, \ldots, M$ and $j = 1, 2, \ldots, N$.

2.4 Image Recovery

With the marked contrast-enhanced image **W**, the original image **X** can be losslessly recovered. We first extract the LSBs from the excluded eight pixels and recover the value s_L. With this value, part of the hidden bits can be extracted from **W** by

$$b_k = \begin{cases} 1, \text{ if } Z(i,j) = s_L + 1 \\ 0, \text{ if } Z(i,j) = s_L \end{cases} \tag{10}$$

where $k = 1, 2, \ldots, h_Z(s_L) + h_Z(s_L + 1)$.

From these bits, we can recover the values of $\{s_1, s_2, \ldots, s_{L-1}\}$. Accordingly, the other hidden bits can be extracted by

$$b_k = \begin{cases} 1, \text{if } Z(i,j) = g + 1 \\ 0, \text{if } Z(i,j) = g \end{cases}, g \in \{s_1, \ldots, s_{L-1}\} \tag{11}$$

where $k \in [h_Z(s_L) + h_Z(s_L + 1) + 1, 8L + 8(J+1) + m_a]$.

Meanwhile, we remove the hidden bits from **W** to reconstruct the image **Z** by

$$Z(i,j) = \begin{cases} W(i,j) - 1, & \text{if } W(i,j) \in S' \\ W(i,j), & \text{otherwise} \end{cases} \tag{12}$$

where $S' = \{s_1 + 1, s_2 + 1, \ldots, s_L + 1\}$.

According to the values of $\{k_1, k_2 + 1, \ldots, k_i + i - 1, \ldots, k_J + J - 1\}$, we shrink the histogram of image **Z** by

$$Y(i,j) = \begin{cases} Z(i,j) - J, & \text{if } Z(i,j) > k_J + J - 1 \\ Z(i,j) - t + 1, & \text{if } Z(i,j) = k_t + t - 1 \\ Z(i,j) + t, & \text{if } k_t + t - 1 < Z(i,j) < k_{t+1} + t \\ Z(i,j), & \text{otherwise} \end{cases} \tag{13}$$

where $t \in [1, J-1], i = 1, 2, \ldots, M$ and $j = 1, 2, \ldots, N$. Thus, the existing gray-levels in **Y** belongs to $\{0, 1, \ldots, 255 - J - 1\}$.

From the extracted bits, we can identify the set $Z = \{z_i | z_i \in [0, 255], i = 0, 1, \ldots, J-1\}$. Accordingly, the supplementary set $\{p_0, p_1, \ldots, p_{255-J-1}\}$ can be identified, where $p_0 < p_1 < \ldots < p_{255-J-1}$. Thus, the image $\mathbf{X}'$ can be reconstructed by

$$X'(i,j) = p_k, \text{ if } Y(i,j) = k \tag{14}$$

where $k = 0, 1, \ldots, 255-J-1, i = 1, 2, \ldots, M$ and $j = 1, 2, \ldots, N$.

Also, compressed bits of the binary map **M** can also be separated from the extracted bits. Using the *arithmetic decoding* algorithm, the original map **M** can be reconstructed. Subsequently, we recover the original image **X** using

$$X(i,j) = \begin{cases} X'(i,j) + 1, & \text{if } M(i,j) = 1 \\ X'(i,j), & \text{if } M(i,j) = 0 \end{cases} \tag{15}$$

where $i = 1, 2, \ldots, M$ and $j = 1, 2, \ldots, Nn$.

3 Experimental Results

To evaluate the proposed method, we implemented the reversible algorithm in many images. Two examples are shown in Figs. 3 and 4. In these experiments, we use the parameter T = 50. Figures 3(a) and 4(a) are the original images containing 512 × 512

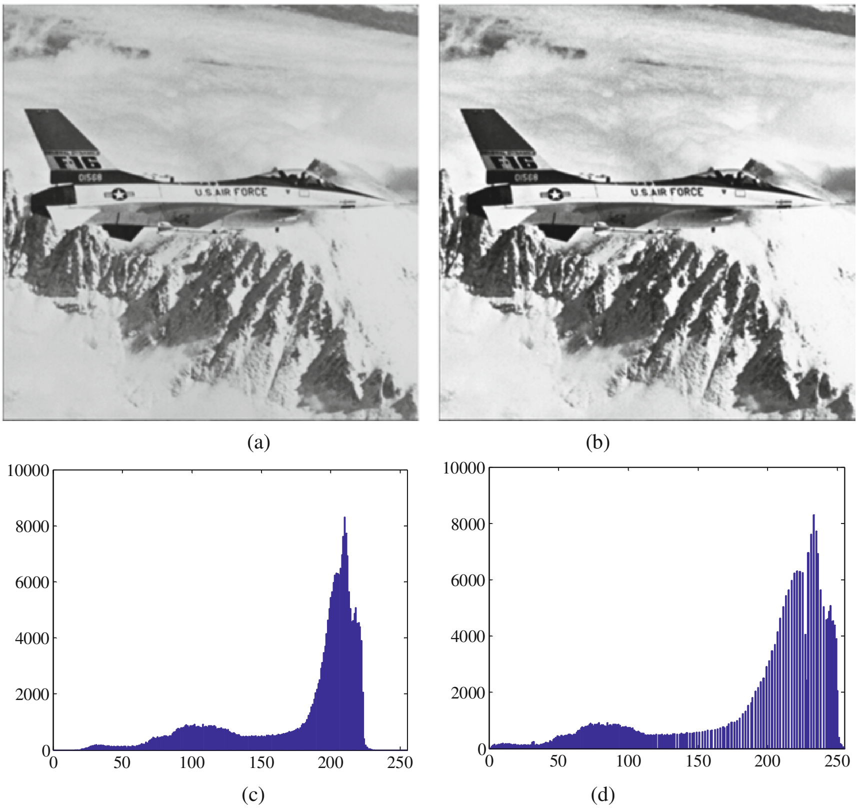

Fig. 3. Reversible contrast enhancement for airplane, (a) is the original image, (b) the processed, (c) the histogram of (a), and (d) the histogram of (b).

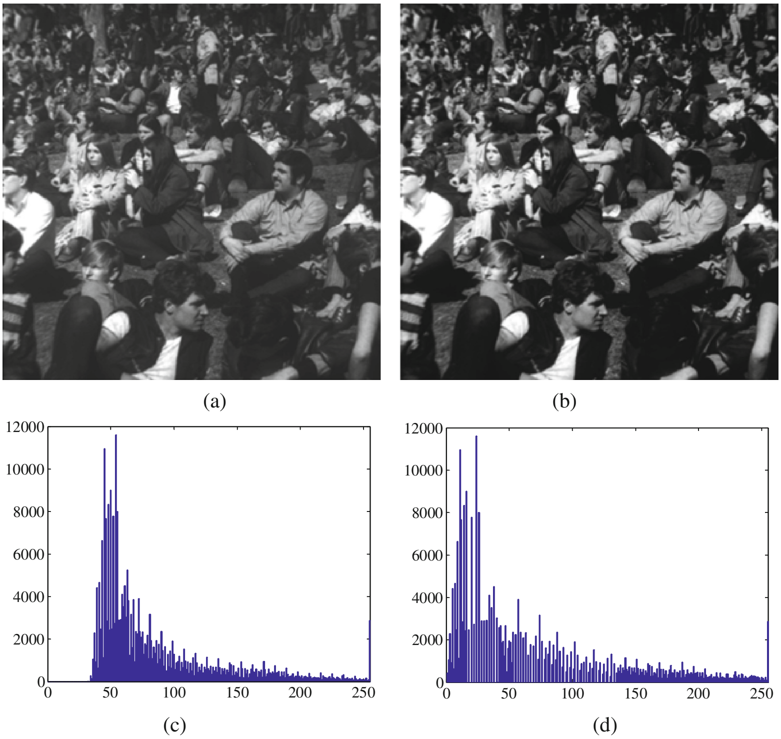

Fig. 4. Reversible contrast enhancement for crowd, (a) is the original image, (b) the processed, (c) the histogram of (a), and (d) the histogram of (b).

pixels, while Figs. 3(b) and 4(b) are the contrast-enhanced image. Histograms of the processed images are shown in Figs. 3(d) and 4(d). Compared with the original histograms in Figs. 3(c) and 4(c), contrasts of the processed images are better than the original images. The proposed method is reversible. After extracting the sided information from Figs. 3(b) and 4(b), the original image can be losslessly recovered, which are identical to Figs. 3(a) and 4(a), respectively.

We use the *expected measure of enhancement by gradient* [5] (EMEG) to assess the contrast of the processed image. EMEG is computed as

$$\mathrm{EMEG}(\mathbf{A}) = \frac{1}{k_1 k_2}\sum\nolimits_{i=1}^{k_1}\sum\nolimits_{j=1}^{k_2}\frac{1}{\beta}\max\left(\frac{A_{i,j}^{dx,h}}{A_{i,j}^{dx,l}+\varepsilon},\frac{A_{i,j}^{dy,h}}{A_{i,j}^{dy,l}+\varepsilon}\right) \tag{16}$$

In (16), $\mathbf{A}$ is the image to be evaluated, which is divided into $k_1 k_2$ overlapping blocks of size 8 × 8. $A_{i,j}^{dx,h}$ and $A_{i,j}^{dx,l}$ are respectively the maximum and minimum of the absolute derivative values in x direction of block $A_{i,j}$, while $A_{i,j}^{dy,h}$ and $A_{i,j}^{dy,l}$ are computed in y direction. $\beta = 255$ is the weighting coefficient and ε is a constant to avoid division by zero. We use $\varepsilon = 1$ in the experiments. The evaluation result $\mathrm{EMEG}(\mathbf{A}) \in [0,1]$.

Table 1. I contrast and quality of the enhanced images using EMEG, SSIM and PSNR

		Original	Imadjust	Histeq	Adapthisteq	SECE	Proposed
Lena	EMEG	0.087	0.126	0.149	0.173	0.118	0.118
	SSIM	—	0.91	0.87	0.78	0.95	0.95
	PSNR	—	21.9	19.1	18.9	23.4	24.0
Baboon	EMEG	0.206	0.314	0.434	0.387	0.275	0.270
	SSIM	—	0.92	0.81	0.75	0.96	0.96
	PSNR	—	19.6	17.6	17.1	21.9	23.5
Barbara	EMEG	0.121	0.156	0.197	0.208	0.149	0.150
	SSIM	—	0.93	0.91	0.81	0.96	0.96
	PSNR	—	24.3	20.8	17.1	25.8	26.1
Crowd	EMEG	0.121	0.142	0.204	0.196	0.155	0.155
	SSIM	—	0.78	12.9	0.80	0.80	0.82
	PSNR	—	18.6	12.9	18.7	19.8	21.0
Pepper	EMEG	0.104	0.130	0.157	0.190	0.126	0.126
	SSIM	—	0.97	0.91	0.80	0.98	0.98
	PSNR	—	21.2	20.7	18.8	22.3	23.3
Sailboat	EMEG	0.142	0.181	0.194	0.246	0.171	0.173
	SSIM		0.94	0.91	0.79	0.98	0.97
	PSNR		23.1	24.5	17.9	24.7	24.1

Images with higher contrast have larger EMEG values. Meanwhile, we use SSIM [7] and PSNR to measure the quality of processed image. SSIM indicates the structure similarity between the processed image and the original image, and PSNR represents the modification of the processing. The larger values of SSIM and PSNR are, the better qualities of the processed images have.

The proposed **RCE** method is compared with the traditional contrast enhancement methods, including *imadjust*, *histeq*, *adapthisteq* algorithms in Matlab system, and *SECE* in [5]. We use the parameter $T = 30$. Experimental results are shown in Table 1. Both contrast and quality of the proposed method are close to *SECE*, meaning that the **RCE** processed image preserves good contrast and good quality. Though the contrast of *imadjust*, *histeq* and *adapthisteq* are larger than the proposed method, quality of the processed method is better. Most importantly, the proposed method is reversible, *i.e.*, the original image can be recovered.

We also evaluate the impact when using different values of parameter T. The results are shown in Fig. 5, in which the parameter T ranges from 30 to 90. EMEG values in Fig. 5(a) show that the contrast increases when we use larger T. Contrarily, SSIM values in Fig. 5(b) show that larger T could result in the lower quality. This indicates that effect of **RCE** can be controlled by T.

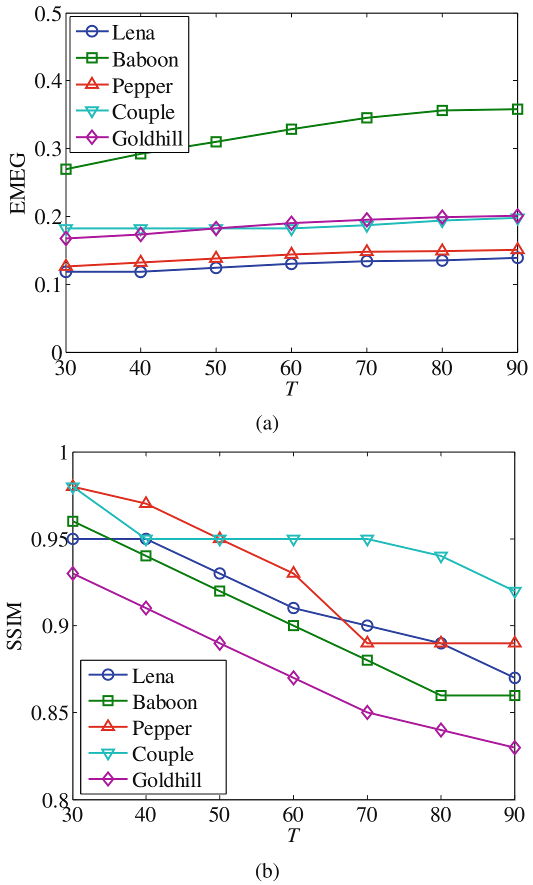

Fig. 5. Contrast and quality corresponding different parameters, (a) shows the EMEG measurement and (b) the SSIM

4 Conclusions

In this paper, we propose a novel idea of reversible image processing, which is different from the traditional image processing. We provide an example of reversible contrast enhancement to show that RIP can be achieved by combining data hiding with image processing. We enhance the original image by histogram shrink and contrast stretching. Meanwhile, some side information is generated and hidden into the contrast-enhanced image. With the processed image, we can losslessly recover the original image. Experimental results show that the proposed method provides good contrast and quality for the contrast-enhanced image. We believe that RIP would be a new research topic for image processing. Other reversible methods for denoising and restoration can also be investigated in the future.

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