A Novel Criterion for Quality Improvement of JPEG Images Based on Image Database and Re-application of JPEG

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***Abstract*—Image compression is one of important technologies in the fields of image processing. JPEG has been commonly used for image compression. Since JPEG is a lossy compression method, decoded images exhibit visually unwanted noises. A need for techniques for improving the quality of JPEG images remains because there still exist many images compressed by JPEG today. Many methods for improving the quality of JPEG images have been proposed. Among them, a method based on re-application of JPEG, which means compression and decoding, is recognized as one of efficient methods. In our previous study, we improved this method by incorporating an image database and novel distance measures between two images. In this paper, we propose a new distance measure between two images to improve the performance of our previous method. We also show some results of numerical experiments to verify the efficacy of the proposed criterion.**

I. Introduction

Image coding is one of indispensable technologies in the fields of image processing in terms of efficient transmission and storing of images. Since there are various highly efficient image compression methods ([1] for instance) today, we can compress a given image by those methods efficiently. However, many existing compressed images were compressed by the conventional JPEG. Since JPEG is a lossy compression method, undesired artifacts appear in decoded images such as so-called block noise and mosquito noise. Thus, a technique for improving the quality of JPEG images, especially with images with low-bit rates, is in demand. Many methods which eliminate these noises and improve the quality of JPEG images have been proposed [2], [3], [4]. Especially, re-application of JPEG method [4], proposed by Nosratinia, is recognized as a simple and effective method. This method adopt a weighted sum of images constructed by re-application of JPEG, which means compression and decoding, to various shifted version of a given JPEG image. However, some images might not be improved effectively since fixed coefficients for weighted sum are used regardless of images.

For this problem, in our previous study [5], we proposed a method for constructing better coefficients from an image in database that has similar properties to the given one and is automatically selected by a criterion, and we confirmed that this method has higher performance.

In this paper, we propose a new criterion, which uses a matrix composed of shifted images, in order to improve the performance of our method. We also verify the efficacy of the proposed criterion by numerical experiments.

The rest of the paper is organized as follows. Section II describes Nosratinia's method and points out problems of this method. Section III explains our method using image database [5]. Section IV describes the conventional criterion for similar image selection adopted in [5] and our new proposed criterion. In section V, numerical experiments are presented in order to compare the proposed criterion with the conventional one. Finally in section VI, we present conclusions.

II. Nosratinia's method [4]

Let $\hat{\boldsymbol{x}}$ and Q denote the decoded image and the quantization table of a given JPEG data, and let $J(Q)$ be the JPEG compression-decoding process by Q. Then, the decoded image $\hat{\boldsymbol{x}}$ is expressed by

$$\hat{\boldsymbol{x}} = J(Q)\boldsymbol{x}, \tag{1}$$

where $\boldsymbol{x}$ is an original image of $\hat{\boldsymbol{x}}$. Let $T = \{-3, -2, \ldots, 3, 4\}$ and let S be the direct product of T, written as $S = \{(i, j) \mid i, j \in T\}$. The number of elements in S is obviously $|S| = 64$. A symbol $k \in \{1, \ldots, 64\}$ is used as index of the element of S. Let D_k denote an image shifting operator in vertical and horizontal directions by (i, j) corresponding to k, which includes completion of the lost pixels caused by the shifting operation, and let D_k^{-1} be an image shifting operator by $(-i, -j)$ that negates the effects of D_k. On these preparation, Nosratinia's method [4] formulates quality improvement of $\hat{\boldsymbol{x}}$ by

$$\boldsymbol{y} = \sum_{k=1}^{64} \alpha_k D_k^{-1} J(Q) D_k \hat{\boldsymbol{x}}. \tag{2}$$

At the beginning, it newly applies re-application of JPEG to various shifted (64 kinds) versions of the given JPEG image. Then, these images are put back into place. Hereafter, we call these replaced images "boundary-shift images". Finally, the quality improved image $\boldsymbol{y}$ is obtained by taking the weighted sum of the boundary-shift images. α_k represents a coefficient for the weighted sum which corresponds to the k-th boundary-shift image. The above process is expected to improve image quality because it spreads block noise and mosquito noise in the JPEG image. Equation (2) is also expressed as the product

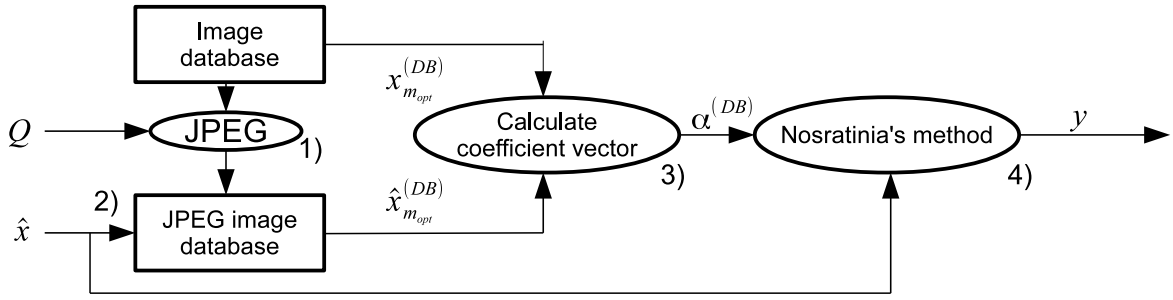

Fig 1. The block diagram of our method given in [5].

of the matrix composed of 64 boundary-shift images and the column vector composed of coefficients as follows.

$$\boldsymbol{y} = X(Q, \hat{\boldsymbol{x}})\boldsymbol{\alpha}, \tag{3}$$

$$\begin{aligned} X(Q, \hat{\boldsymbol{x}}) &= [D_1^{-1}J(Q)D_1\hat{\boldsymbol{x}}, \ldots, D_{64}^{-1}J(Q)D_{64}\hat{\boldsymbol{x}}], \\ \boldsymbol{\alpha} &= [\alpha_1, \ldots, \alpha_{64}]^T, \end{aligned}$$

where the superscript ^{T} denotes the transposition operator.

In [4], two methods of setting α_k were proposed. One is the way using the uniform coefficient $1/64$. Although this method is very simple, a given JPEG image is not enhanced sufficiently in some cases because the same coefficients are used for all images. The other is the way deciding by MMSE estimation with a training image set. There is some possibility of effective improvement of image quality by changing elements in the training image set. However, it is not mentioned how to compose a proper training image set for a given image.

III. Improving image quality method with database [5]

In Nosratinia's method [4], the optimal coefficient vector which minimizes the mean squared errors (MSE) between the original image $\boldsymbol{x}$ and the corresponding JPEG image $\hat{\boldsymbol{x}}$ is expressed as

$$\begin{aligned} \boldsymbol{\alpha}^{(OPT)} &= \arg\min_{\boldsymbol{\alpha}} ||X(Q, \hat{\boldsymbol{x}})\boldsymbol{\alpha} - \boldsymbol{x}||^2 \\ &= (X(Q, \hat{\boldsymbol{x}})^T X(Q, \hat{\boldsymbol{x}}))^+ X(Q, \hat{\boldsymbol{x}})^T \boldsymbol{x}, \end{aligned} \tag{4}$$

where the superscript $^+$ denotes the Moore-Penrose generalized inverse of a matrix [6]. Nosratinia's method is able to provide the best performance with $\boldsymbol{\alpha}^{(OPT)}$. However, of course $\boldsymbol{x}$ is unknown. Thus, it is impossible to obtain $\boldsymbol{\alpha}^{(OPT)}$. For this problem, we proposed a method by using image database in [5]. Our method attempts to improve the quality of JPEG image $\hat{\boldsymbol{x}}$ by the optimal coefficient vector for the image in a given image database which is the most similar to $\hat{\boldsymbol{x}}$. The algorithm of our method given in [5] is constructed as follows.

1) Apply $J(Q)$ to each of images in the image database $\mathrm{DB} = \{\boldsymbol{x}_1^{(DB)}, \ldots, \boldsymbol{x}_n^{(DB)}\}$ to make the JPEG image database $\hat{\mathrm{DB}} = \{\hat{\boldsymbol{x}}_1^{(DB)}, \ldots, \hat{\boldsymbol{x}}_n^{(DB)}\}$
2) Select $\hat{\boldsymbol{x}}_{m_{opt}}^{(DB)}$, the most similar image to input image $\hat{\boldsymbol{x}}$, in $\hat{\mathrm{DB}}$ by a criterion (described in section IV)
3) Calculate $\boldsymbol{\alpha}^{(DB)}$, the optimal coefficient vector for $\hat{\boldsymbol{x}}_{m_{opt}}^{(DB)}$, by $\hat{\boldsymbol{x}}_{m_{opt}}^{(DB)}$ and corresponded original image $\boldsymbol{x}_{m_{opt}}^{(DB)} \in \mathrm{DB}$ from (4).
4) Obtain the improved image by Nosratinia's method with $\boldsymbol{\alpha}^{(DB)}$.

Figure 1 shows the outline of the above algorithm. Note that the point at issue in this paper is a construction of a criterion used in the step 2) in the above algorithm.

IV. Similar image selection

For selection of $\hat{\boldsymbol{x}}_{m_{opt}}^{(DB)}$ from the JPEG image database $\hat{\mathrm{DB}}$, we employed an effective method in [5]. This method adopts the covariance matrices of block images. In this paper, we propose a novel image selection method, using $X(Q, \hat{\boldsymbol{x}})^T X(Q, \hat{\boldsymbol{x}})$ used in (4).

In the conventional method given in [5], we partition the input image $\hat{\boldsymbol{x}}$ into $s \times s$ pixel size block, regard each of blocks as a column vector, and calculate the covariance matrix $\Sigma^{(INPUT)}$ from these vectors. Then, we obtain $\Sigma_m^{(DB)}$, the covariance matrix from each of images $\hat{\boldsymbol{x}}_m^{(DB)}$ in $\hat{\mathrm{DB}}$ in the same way. On the basis of the above preparations, we select the index of the optimal database image as

$$m_{opt} = \arg\min_m \left\| \frac{\Sigma^{(INPUT)}}{\mathrm{tr}(\Sigma^{(INPUT)})} - \frac{\Sigma_m^{(DB)}}{\mathrm{tr}(\Sigma_m^{(DB)})} \right\|_F, \tag{5}$$

where $||\cdot||_F$ denotes the Frobenius norm of a matrix and $\mathrm{tr}(\cdot)$ denotes the trace of a matrix, respectively. We adopt $s = 8$, that is the same as the DCT block size used in JPEG compression, in numerical experiments in the following section. Let $\boldsymbol{\alpha}^{(\Sigma)}$ denote the coefficient vector obtained by this method, and the evaluation criterion of the right-hand side of (5) is called "criterion Σ" hereafter.

In the proposed method, we make the matrix composed of 64 boundary-shift images $X(Q, \hat{\boldsymbol{x}})$ from $\hat{\boldsymbol{x}}$ and calculate $Y^{(INPUT)} = X(Q, \hat{\boldsymbol{x}})^T X(Q, \hat{\boldsymbol{x}})$. Then, we obtain $Y_m^{(DB)}$ from each of images $\hat{\boldsymbol{x}}_m^{(DB)}$ in $\hat{\mathrm{DB}}$ in the same way. On the basis of the above preparations, we select the index of the

Fig 2. The original image.

Fig 3. A decoded JPEG image.

Fig 4. The improved image by $\boldsymbol{\alpha}^{(\Sigma)}$.

Fig 5. The improved image by $\boldsymbol{\alpha}^{(Y)}$.

optimal database image as

$$m_{opt} = \arg\min_{m} \left\| \frac{Y^{(INPUT)}}{\mathrm{tr}(Y^{(INPUT)})} - \frac{Y_m^{(DB)}}{\mathrm{tr}(Y_m^{(DB)})} \right\|_F . \quad (6)$$

Let $\boldsymbol{\alpha}^{(Y)}$ denote the coefficient vector obtained by the proposed method, and the evaluation criterion of the right-hand side of (6) is called "criterion Y".

V. Numerical experiments

We conduct experiments for comparing criterion Y with criterion Σ to verify the efficacy of the new proposed criterion.

A. Conditions for the experiment

We adopt 6 images with 512×512 pixels and 256 gray scale (Airplane, Goldhill, Lenna, Mandrill, Milkcrown, Pepper) and, 6 images with 256×256 pixels and 256 gray scale (Barbara, Boat, Building, Cameraman, Lax, Lighthouse) as test images. Input images are obtained by application of JPEG compression and decoding to the test images with quantization tables $Q_1 \sim Q_3$ shown in Table I. Note that Q_1 gives an image with high bit-rates, Q_3 gives an image with low bit-rates, and Q_2 gives an image with intermediate bit-rates. As database images, 252 gray scale natural images (different from the test images) are used.

B. An example of the improved image

We take the test image "Boat" for an example of the comparison of the performance of $\boldsymbol{\alpha}^{(\Sigma)}$ with that of $\boldsymbol{\alpha}^{(Y)}$. The input image is made with the quantization table Q_2. The original image is shown in Fig. 2 and Fig. 3 shows the input image, that is, the decoded image. The improved image by $\boldsymbol{\alpha}^{(\Sigma)}$ is shown in Fig. 4, and the improved image by $\boldsymbol{\alpha}^{(Y)}$ is shown in Fig. 5. The result shows that the improved image by $\boldsymbol{\alpha}^{(Y)}$ is more effectively denoised and clearer than the improved image by $\boldsymbol{\alpha}^{(\Sigma)}$.

TABLE I
QUANTIZATION TABLES USED IN NUMERICAL EXPERIMENTS.

Q_1								Q_2								Q_3							
20	24	28	32	36	80	98	144	50	60	70	70	90	120	255	255	110	130	150	192	255	255	255	255
24	24	28	34	52	70	128	184	60	60	70	96	130	255	255	255	130	150	192	255	255	255	255	255
28	28	32	48	74	114	156	190	70	70	80	120	200	255	255	255	150	192	255	255	255	255	255	255
32	34	48	58	112	128	174	196	70	96	120	145	255	255	255	255	192	255	255	255	255	255	255	255
36	52	74	112	136	162	206	224	90	130	200	255	255	255	255	255	255	255	255	255	255	255	255	255
80	70	114	128	162	208	242	200	120	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
98	128	156	174	206	242	240	206	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255
144	184	190	196	224	200	206	208	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255	255

TABLE II
CORRELATION COEFFICIENTS OF THE CRITERIA AND IPSNR.

Q_1 image	Airplane	Goldhill	Lenna	Mandrill	Milkcrown	Pepper	Barbala	Boat	Building	Cameraman	Lax	Lighthouse
Σ	-0.500	-0.548	-0.583	-0.458	-0.592	-0.412	-0.574	-0.583	-0.592	-0.574	-0.529	-0.574
Y	-0.752	-0.861	-0.752	-0.649	-0.704	-0.582	-0.813	-0.908	-0.889	-0.892	-0.782	-0.893
Q_2 image	Airplane	Goldhill	Lenna	Mandrill	Milkcrown	Pepper	Barbala	Boat	Building	Cameraman	Lax	Lighthouse
Σ	-0.451	-0.581	-0.612	-0.429	-0.617	-0.479	-0.581	-0.589	-0.585	-0.522	-0.497	-0.532
Y	-0.679	-0.592	-0.899	-0.484	-0.636	-0.541	-0.769	-0.877	-0.867	-0.860	-0.640	-0.805
Q_3 image	Airplane	Goldhill	Lenna	Mandrill	Milkcrown	Pepper	Barbala	Boat	Building	Cameraman	Lax	Lighthouse
Σ	-0.537	-0.534	-0.528	-0.593	-0.782	-0.716	-0.560	-0.241	-0.541	-0.522	-0.345	-0.472
Y	-0.806	-0.812	-0.826	-0.687	-0.825	-0.816	-0.763	-0.345	-0.782	-0.815	-0.437	-0.767

TABLE III
IMPROVEMENT IN PSNR.

Q_1 image	Airplane	Goldhill	Lenna	Mandrill	Milkcrown	Pepper	Barbala	Boat	Building	Cameraman	Lax	Lighthouse
Σ	0.624	0.548	0.643	0.281	**-0.272**	0.311	**1.040**	0.794	0.562	0.508	**0.314**	0.423
Y	0.624	**0.574**	**0.645**	**0.299**	-1.076	0.311	1.039	**0.860**	**0.725**	**0.513**	0.313	**0.430**
Q_2 image	Airplane	Goldhill	Lenna	Mandrill	Milkcrown	Pepper	Barbala	Boat	Building	Cameraman	Lax	Lighthouse
Σ	**0.799**	**0.753**	**0.960**	**0.336**	**0.412**	0.592	0.850	0.834	**0.777**	**0.583**	0.253	0.453
Y	0.627	0.708	0.954	0.334	0.208	0.592	**0.865**	**0.921**	0.765	0.576	**0.272**	**0.465**
Q_3 image	Airplane	Goldhill	Lenna	Mandrill	Milkcrown	Pepper	Barbala	Boat	Building	Cameraman	Lax	Lighthouse
Σ	0.945	0.914	1.100	**0.464**	**1.025**	**1.195**	0.868	0.377	0.771	**0.725**	**0.378**	**0.640**
Y	**1.035**	**0.925**	**1.102**	0.449	1.011	0.972	0.868	**0.860**	**0.801**	0.709	0.361	0.600

C. Objective evaluation

Firstly, we investigate the correlation between the criteria $\Sigma_m^{(DB)}, Y_m^{(DB)}$ and the improvement in PSNR (IPSNR) defined as

$$IPSNR_m = 10\log\frac{||\boldsymbol{x}||^2}{||\boldsymbol{x}-\boldsymbol{y}_m||^2} - 10\log\frac{||\boldsymbol{x}||^2}{||\boldsymbol{x}-\hat{\boldsymbol{x}}||^2} \quad (7)$$

where $\boldsymbol{x}$ denotes the fixed test image from 12 test images and $\boldsymbol{y}_m$ denotes the corresponding improved image obtained by m-th image in the JPEG image database, that is,

$$\boldsymbol{y}_m = X(Q,\hat{\boldsymbol{x}})\boldsymbol{\alpha}_m^{(DB)}, \quad (8)$$

in which $\boldsymbol{\alpha}_m^{(DB)}$ is constructed by (4) with $\boldsymbol{x}_m^{(DB)}$ and $\hat{\boldsymbol{x}}_m^{(DB)}$. It is expected to obtain a better denoised image if each criterion has a strong negative correlation with IPSNR since the smaller the criterion is, the higher IPSNR is obtained. Table II shows the correlation coefficients of $\Sigma_m^{(DB)}$ and $IPSNR_m$ and those of $Y_m^{(DB)}$ and $IPSNR_m$, calculated by 252 images in the database, for each test images. According to these results, it is confirmed that the criterion Y has stronger correlation than criterion Σ in all cases.

Nextly, we show IPSNR of the improved images by $\boldsymbol{\alpha}^{(\Sigma)}$ and $\boldsymbol{\alpha}^{(Y)}$ in Table III. According to Table III, it is confirmed that $\boldsymbol{\alpha}^{(Y)}$ yields fair results with $\boldsymbol{\alpha}^{(\Sigma)}$.

VI. CONCLUSION

In this paper, we proposed a new criterion that measures similarity of images in the quality improvement method of JPEG images based on an image database and re-application of JPEG. We verified the efficacy of the proposed criterion by numerical experiments and confirmed that our new criterion has strong correlation with IPSNR. Clarifying the reason why this strong correlation does not lead a higher IPSNR is one of our future works.

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