IMAGE RESTORATION USING SIMILAR REGION SEARCH AND DIGITAL WATERMARK

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***Abstract*—Baroumand et al. proposed the image restoration method using the correlation of the image, which is called the watermark driven decentralized best matching (WDBM). In this method, the most similar region for each block is searched and the position information of the most similar region is embedded as digital watermark. However, in some cases, a part of pixels in the corrupted block cannot be restored by WDBM. In this paper, we propose an image restoration method that embeds the position information of the similar region into the block which is located away from the current block at regular intervals. The proposed method can restore all pixels in the corrupted block with a high probability and improve the restoration rate.**

I. INTRODUCTION

In recent years, we have a greater opportunity to transmit the digital contents including still images and videos through a network. In order to use the network effectively, large image files are compressed to reduce their redundancy. A number of image/video compression standards such as JPEG [1], JPEG2000 [2] and H.264 [3] are widely utilized.

However, the image data compressed by JPEG is sensitive to the transmission error. If a bit error occurs in the transmission of a compressed image, block errors are found in the decoded image since the basic coding unit of JPEG is an 8×8 block. Therefore, the image quality is severely degraded. Even if the data of the corrupted block is re-sent after detecting the block error, there still exists a risk of the error when the transmission channel is not reliable.

To solve these problems, several image restoration methods using error concealment techniques have been proposed [4]-[12]. These methods utilize the non-corrupted regions in the decoded image. These methods are based on the fact that the pixel values of the natural images have high correlation, i.e., if the natural image is divided into small blocks, we can find some similar regions in the image for each block. Therefore, several methods utilizes this characteristic to restore the decoded image containing the block errors. The similarities in an image can be categorized into two types; the *centralized similarities* which indicate the local correlations of micro regions, and the *decentralized similarities* which indicate the scattered correlations over the image. The most of the image restoration methods rely on the centralized similarities [7]-[12]. These methods utilize neighboring pixels of the corrupted region and some interpolation methods to restore it.

On the other hand, the restoration methods using the decentralized similarities utilize the digital watermarking techniques [4]-[6]. In these methods, the watermark information taking the decentralized similarities into account is embedded in the image at the encoder. When this image is corrupted by a transmission error, the corrupted regions can be restored by using the watermark information extracted from the uncorrupted regions of this image. That is, the watermark information play a role of the error correcting code in these method. With regard to the restoration method utilizing the watermarking, Baroumand et al. proposed the *watermark driven decentralized best matching* (WDBM) [4].

WDBM addresses the case that an image in JPEG format is corrupted during the transmission in high packet loss condition and block errors are appeared in the image. Therefore, it is assumed that the shape of the corrupted regions is square in WDBM. In WDBM, an image is divided into non-overlapping blocks of the same size of 8×8 pixels as is used in JPEG, and the similar region for each block is searched in this image. In addition, the position information of the similar region is embedded by using the watermarking scheme [13][14] in the block itself. However, WDBM has a drawback that some pixels in the corrupted block are possibly not restored although a part of the corrupted block can be restored.

In this paper, in order to improve the probability to restore all pixels in the corrupted block, we propose a method to embed the position information not into the current block itself but into the other block like [15]. The watermarking method proposed by Patra et al. [15] selects the embedding block randomly and needs the same random seed used in the embedding process in extracting the embedded information. On the other hand, the proposed method uses a block locating a certain distance away from the current block as the embedding block. Therefore, the similar region of the corrupted block may be able to be utilized to restore the corrupted block because the position information of the similar region is embedded in the embedding block. As a result, all pixels in the corrupted block can be restored and the restoration performance can also be improved. We compared our method with WDBM with respect to the quality of the watermarked image, the restoration efficiency, and the computation complexity.

The rest of this paper is organized as follows. Section II

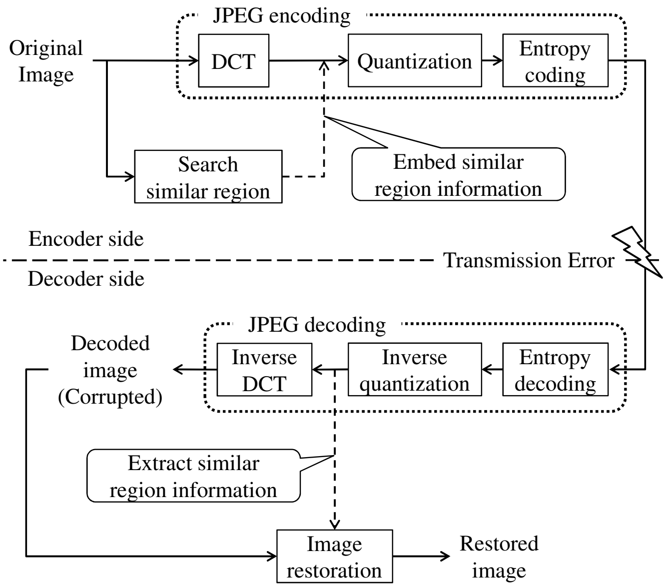


Fig. 1. Overview of WDBM.

describes WDBM, and Section III is the proposed method. The experimental results are described Section IV, and Section V concludes this paper.

II. WATERMARK DRIVEN DECENTRALIZED BEST MATCHING

WDBM [4] is the image restoration method using the digital watermark technique. Fig. 1 shows the overview of WDBM.

A. Encoder Side

In the encoder side, firstly, an image is divided into non-overlapping *basic blocks* of 8×8 pixels. Then, a *similar region* which is similar to each basic block is searched in the image. The similar region is a region of 8×8 pixels which gives the minimum MSE with respect to the basic block. The similar region may overlap with up to four basic blocks.

When the similar region for each basic block is detected, the position information of the similar region is embedded in the corresponding basic block. In order to take account of JPEG compression, the position information is embedded in DCT domain of the basic block. The embedding method is the *quantization index modulation* (QIM) [14] which uses the following equation:

$$P^{'}_{i,j} = q_{i,j} \times \left\{ b_k + 2 \times round\left(\frac{P_{i,j} - b_k}{2 \times q_{i,j}} \right) \right\} \tag{1}$$

where $P_{i,j}$ and $P^{'}_{i,j}$ are the DCT coefficients of the position of DCT domain (i, j), $(0 \leq i \leq 7, 0 \leq j \leq 7)$, and the watermarked DCT coefficient, respectively. $q_{i,j}$ represents the corresponding quantization step of the position (i, j) and it is the same quantization step as used in JPEG compression process. The variable b_k is the k-th bit of the binary representation of the position information. The size of the position information embedded in the block depends on the search range of the similar region. If the search range is $M \times N$ [pixel], the size of the position information is $\lceil \log_2 M \rceil + \lceil \log_2 N \rceil$ [bit]. After the embedding process of (1), the entropy coding on the JPEG compression process is performed and the encoded data is transmitted through the network.

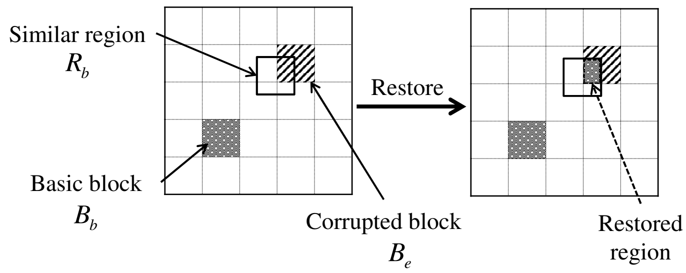


Fig. 2. Example of restoration by WDBM.

B. Decoder Side

In the decoder side, the first step is to decode the received image using JPEG decoder. However, when the image is transmitted through the unreliable network, the transmitted image would be corrupted. As described in Section II-A, the position information of the similar region is embedded in each basic block of the received JPEG image. Therefore, the corrupted image can be restored by using these information. Also, the positions of the corrupted blocks are considered to be readily detected by using packet error control coding techniques [16].

As shown in Fig. 1, the position information are extracted from all non-corrupted basic blocks after the inverse quantization process in the JPEG decoder. The extraction process is defined as follows:

$$b_k = \frac{P^{'}_{i,j}}{q_{i,j}} \bmod 2 \tag{2}$$

which is the reverse operation of (1).

Next, the restoration is performed by using the extracted information. As shown in Fig. 2, let us consider the restoration of the corrupted basic block B_e. Here B_b and R_b denote the basic block and its similar region, respectively. If a corrupted region is found in R_b such as in Fig. 2, the basic block where the position information of R_b is embedded is searched. If the intended block, i.e., B_b in Fig. 2, is found, the corresponding pixels of B_b are copied into the corrupted part of R_b. These processes are repeatedly performed until all non-corrupted blocks are utilized.

However, it is generally difficult to restore all corrupted regions only by using WDBM. In order to fill in the remaining corrupted regions which could not be restored by WDBM, the other restoration method utilizing the centralized similarities called the *sequential best range matching* (SBRM) [7] is applied to the corrupted image after WDBM.

SBRM is the image restoration method to recover the corrupted blocks as well as WDBM. In SBRM, firstly, the image is divided into non-overlapping blocks. A block containing any number of corrupted pixels is regarded as the corrupted block. SBRM searches the similar region of the corresponding corrupted block and utilizes it for image restoration. In SBRM, the similarity between two blocks is identified by these enclosing frames. In other words, if two frames are similar, their interior blocks are also recognized as similar. The image restoration of SBRM iterates until all corrupted pixels are filled by similar pixels. The previously restored pixels may be utilized for the restoration of the un-restored pixels. If the previously restored pixels aren't correctly restored, this error propagates the next restored pixels and the performance of image restoration is affected. In order to alleviate this effect, eight searching orientations are used. The final restored image is computed by averaging the restored results using eight orientations.

III. PROPOSED METHOD

In WDBM, the position information of the similar region is embedded in the related basic block. Therefore, when the related basic block is corrupted as well as a part of the similar region, this region cannot be restored. In addition, WDBM does not effectively utilize the uncorrupted region. Even if the basic block is corrupted, its similar region is possibly uncorrupted and usable to restore the basic block if the channel error rate is fairly low. However, WDBM cannot use the similar region because the position information of the similar region is embedded in the corrupted basic block. In order to solve the above problems, we propose a method to restore all pixels of the corrupted block by changing the embedding block.

There are two different points between our method and WDBM. One is the block where the position information is embedded and the other is the restoration process. These are explained in Section III-A. In Section III-B, we compare the ability of restoration between our method and WDBM.

A. Restoration Process of Proposed Method

At first, we explain about the embedding process of the proposed method. In our method, the position information of the similar region is embedded in a basic block which is located in a specified distance from the basic block related the similar region. Let us denote the specified distances as (p, q). Here, p denotes p-th block away from the basic block in horizontal direction and q denotes the q-th block away from the basic block in vertical direction. In this paper, (p, q) is called the *embedding rule*.

Fig. 3 shows an example of the restoration by our method. In Fig. 3, B_b is the basic block and B_e is the corrupted block. R_b is the similar region of B_b and $B_{b\text{-}emb}$ is the block where the position information of R_b is embedded. In the same way, R_e is the similar region of B_e and $B_{e\text{-}emb}$ is the block where the position information of R_e is embedded. In order to restore B_e, our method is applied in two steps described as follows.

1) If $B_{e\text{-}emb}$ is not corrupted, the position information of R_e can be extracted. B_e can be restored by copying R_e to B_e unless R_e is absolutely corrupted. Furthermore, if $B_{e\text{-}emb}$ and R_e are not corrupted at all, all pixels of B_e can be restored completely.
2) If $B_{e\text{-}emb}$ or R_e is corrupted, all pixels in B_e cannot be restored by Step 1. In this case, the restoration process of WDBM is applied to B_e. When there is the corrupted region in R_b as shown in Fig. 3(b), $B_{b\text{-}emb}$ and B_b are searched. If there are both $B_{b\text{-}emb}$ and B_b, the corresponding pixels in B_b are copied in the corrupted pixels in R_b.

In our method, Step 1 is repeatedly applied to all corrupted regions. After that, Step 2 is applied to the corrupted regions which have not been restored by Step 1. Furthermore, in common with WDBM, SBRM is applied to the regions which cannot be restored by our method.

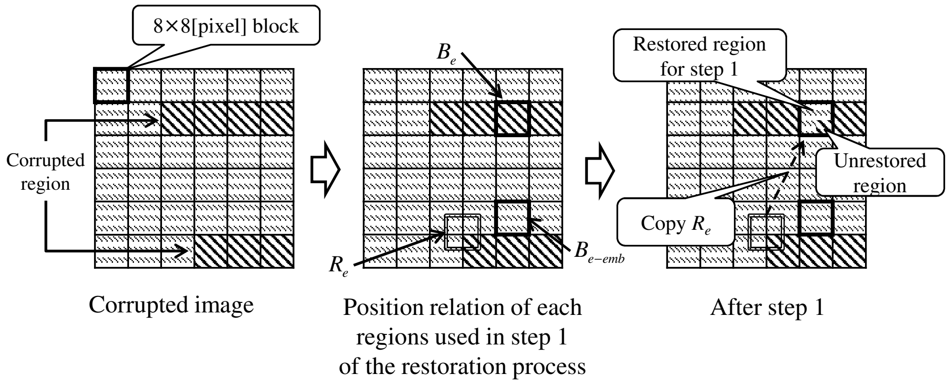
TABLE I
COMPARISON OF WDBM AND THE PROPOSED METHOD

Condition of basic block			Restoration result of B_e			
B_b	$B_{b\text{-}emb}$	$B_{e\text{-}emb}$	WDBM	Proposed		
				case 1	case 2	case 3
E	E	E	PC	C	PC	PC
E	E	NE	PC	PC	PC	PC
E	NE	E	PC	C	PC	NG
E	NE	NE	PC	NG	NG	NG
NE	E	E	NG	C	PC	NG
NE	E	NE	NG	NG	NG	NG
NE	NE	E	NG	C	PC	NG
NE	NE	NE	NG	NG	NG	NG

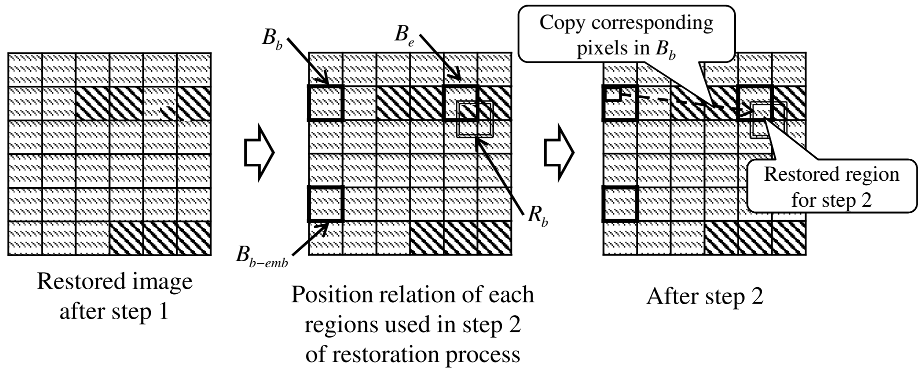
B. Ability of Restoration

Table I shows the comparison of the restoration ability between WDBM and the proposed method. In Table I, the columns of B_b, $B_{b\text{-}emb}$, and $B_{e\text{-}emb}$ show the conditions whether the corresponding basic block exists or not, i.e., "E" and "NE" denote "exist" and "not exist" respectively. The columns of "WDBM" and "Proposed" show the restoration result corresponding to the conditions of the basic blocks as follows: "C" is "B_e can be restored completely", "PC" is "B_e can be restored partly", and "NG" is "B_e cannot be restored". In the three columns about the proposed method, the condition of R_e is represented as follows: the column "case 1" is the case that R_e is not corrupted, the column "case 2" is the case that R_e is corrupted partly, and the column "case 3" is the case that R_e is corrupted entirely.

As shown in Table I, the restored results of WDBM is related with the condition of B_b, that is, if B_b is not corrupted, B_e can be restored. However it is difficult to restore B_e perfectly in WDBM. In the "case 3", the restoration probability of B_e is low in our method. On the other hand, our method has better performance than WDBM in the cases of "case 1" and "case 2" except for the condition of the fourth row from the top because our method utilizes more regions for restoring a corrupted block than WDBM. In addition, when $B_{e\text{-}emb}$ and R_e is not corrupted, B_e can be completely restored with high probability. Therefore, it is expected that the restoration performance of our method will be better when the transmission error rate is relatively low.



(a) Step 1



(b) Step 2

Fig. 3. Example of restoration by the proposed method.

IV. EXPERIMENTAL RESULTS

In order to compare our method to WDBM, we evaluated the quality of the watermarked image and its bit-rate, the restoration efficiency, and the computation complexity. In this experiment, we use three grayscale images *Barbara*, *Lena*, and *Mandrill* (512×512 [pixel]).

A. Quality and Bit-rate of Watermarked Image

The quality parameter (QP) of JPEG is set to 80 and the embedding rule of our method (p, q) is $(30, 30)$. In this experiment, the search range of the similar region is the same as the input image. Hence, the amount of the position information embedded in each basic block is $\log_2 512^2 = 18$ [bit] in case of using the 512×512 image. On the watermarking process using QIM, 1 bit information is embedded in a DCT coefficient. Therefore, 18 DCT coefficients of the basic block are used in this experiment. These DCT coefficients are selected from the lower frequency component except for the DC component. In addition, in order to transmit the encoded image on a noisy channel, the restart markers conformed to the JPEG standard [17] are set to the encoded images. In this experiment, the restart interval is 64 blocks per a marker.

Table II shows the peak signal-to-noise ratio (PSNR) and bit-rate of the watermarked images. These results are the mean value of three images. In Table II, "JPEG" is the encoded image no embedded information. As shown in Table II, PSNR of our method is equal to that of WDBM. The same holds for the bit-rate. The reason why the result of our method is equal to that of WDBM with respect to PSNR and the bit-rate is that the embedding capacity per block is the same in both our method and WDBM. On the other hand, in comparison with unwatermarked JPEG compression image, PSNR of the watermarked image is low and the bit-rate of the watermarked image is increased because of embedding the position information in the image. If the search range of the similar region becomes small, the position information embedded in the block is also small. As a result, the watermarked image will be improved with regard to PSNR and bit-rate. However, considering the image restoration, the search range should not be made smaller because it is difficult to search the best similar region in the image.

TABLE II
PSNR AND BIT-RATE OF WATERMARKED IMAGE

	PSNR[dB]	Bit-rate[bpp]
JPEG	35.91	1.748
Proposed	34.10	1.825
WDBM	34.10	1.823

B. Restoration Efficiency

In this section, assuming that the bit stream of the JPEG format data dealing with Section IV-A is randomly corrupted by the transmission error occurred during the transmission,

Fig. 4. Example of corrupted image (Rate of corrupted blocks: 10%)

basic blocks of the decoded image are corrupted for the experiment. Fig. 4 shows the example of the corrupted image. As shown in Fig. 4, this experiment assumes that the corrupted regions by transmission error are loss of the image data completely. The rate of the corrupted blocks is varied from 1% to 30%. The corrupted images are restored by our method or WDBM. For comparison, we used the restoration rate ρ which is defined as follows:

$$\rho = \frac{n_r}{n_e} \times 100 \qquad (3)$$

where n_e is the number of pixels corrupted by the transmission, and n_r is the number of pixels restored by our method or WDBM. After the restoration process for each method, the remaining corrupted pixels are restored by SBRM and the restored image is evaluated by PSNR. The above experiments are performed 10 times by changing the corrupted basic blocks for each corrupted block rate. The experimental results are the mean values of these results.

Fig. 5 shows the restoration rates by our method and WDBM. In Fig. 5, "Proposed" is the results that add the results of Step 1 to that of Step 2 in our method. In this result, the restoration rate ρ of our method is better than that of WDBM in all rates of corrupted blocks. Fig. 6 shows the enlarged views of *Barbara*. It is clear that fewer corrupted regions are remaining in Fig. 6(c) than Fig. 6(d). Thus, the restoration performance of our method exceeds that of WDBM as shown in Table I.

Then, the quality evaluation of the restored image is shown in Fig. 7. which presents the results applying SBRM to the remaining corrupted regions after the restoration process of our method or WDBM. In Fig. 7, "SBRM" is the result applying SBRM without using our method or WDBM. As shown in Fig. 7, PSNR of the restored image using our method is better than that of WDBM in all cases. Compared with SBRM, PSNR in our method is better than SBRM when the rate of corrupted blocks is higher than 2%.

C. Computational Complexity

In this section, we represent the result about the run times of the image restoration. This experiment is carried out in MATLAB environment running in an Intel(R) Core(TM) i7-2600, 3.40GHz CPU.

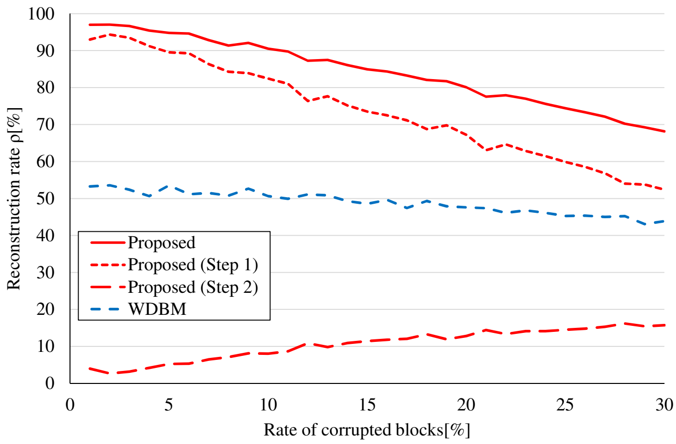
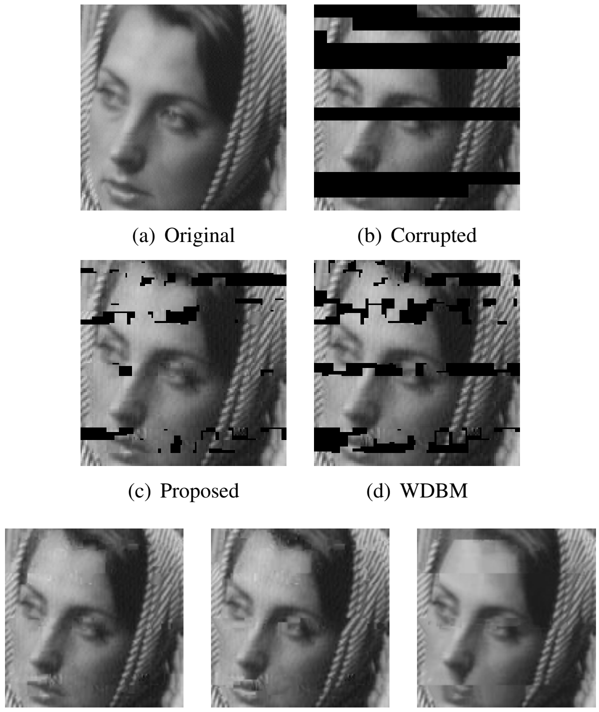


Fig. 5. Restoration rate.



(a) Original (b) Corrupted

(c) Proposed (d) WDBM

(e) Proposed + SBRM (f) WDBM+SBRM (g) SBRM

Fig. 6. Comparison of the restored images (Rate of corrupted blocks: 20%).

Fig. 8 shows the results comparing the run time of the proposed restoration process with that of WDBM. Here, Fig. 8 represents the results before SBRM is applied to the restored image by our method or WDBM. In addition, the run time normalized by SBRM is shown in Fig. 9. As shown in Fig. 8, since the proposed restoration process has two kinds of restoration steps, the run time of our method is twice more than that of WDBM. On the other hand, as shown in Fig. 9, our method requires the shortest times in comparison with WDBM+SBRM or SBRM. For the results of Fig. 9, two reasons are considered as follows: First, SBRM requires more run time than our method and WDBM: Second, our method requires fewer pixels applying SBRM than WDBM since the restored image after our method has fewer corrupted pixels

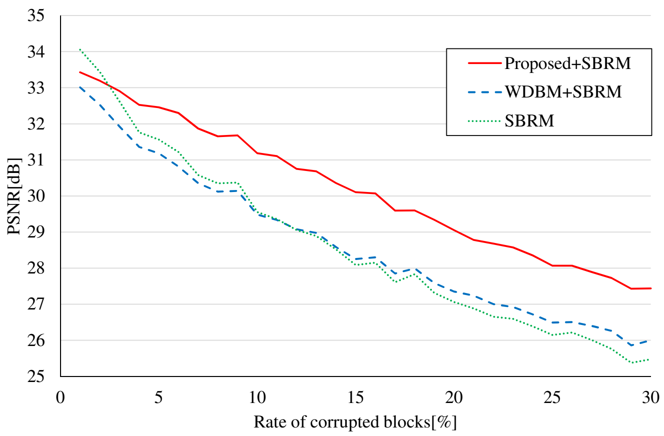


Fig. 7. PSNR of restored image.

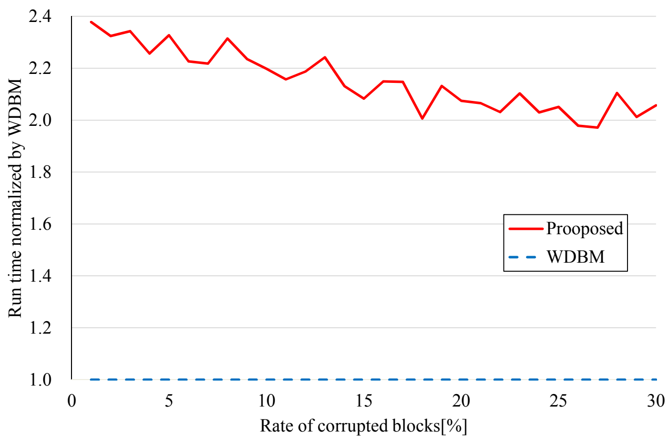


Fig. 8. Run time normalized by WDBM.

than that of WDBM as shown in Fig. 5. Consequently, our method requires the lower computation payload than WDBM or SBRM.

V. CONCLUSION

In this paper, we proposed an image restoration method using digital watermarking. In our method, the position information of the similar region is embedded not into the basic block corresponding to the similar region but into the other basic block. Therefore, our method enabled to raise the probability to restore all pixels in the corrupted block. Moreover, our method can achieve the high restoration performance by using the restoration process based on WDBM. Experimental results show that our method achieves better restoration performance than WDBM in terms of both the restoration rate and the restored image quality. In addition, the run time of our method is shorter than WDBM or SBRM. Future work includes the extension of our method for the color images in order to enhance the universality of the restoration method.

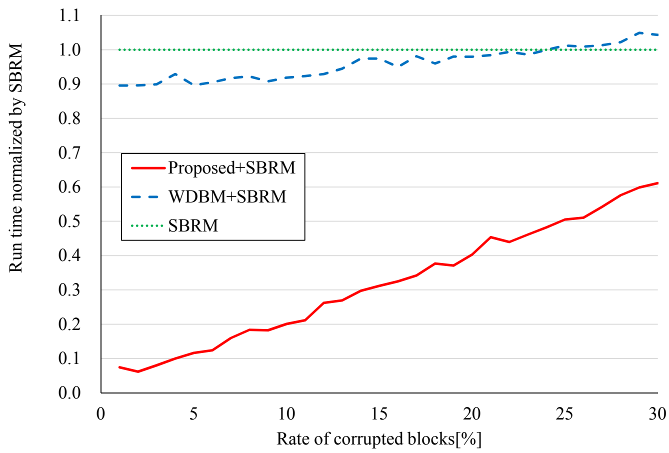


Fig. 9. Run time normalized by SBRM.

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