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IMPORTANT OF CODING PERFORMANCE BY OPTIMAL BASIS SELECTION IN IMAGE COMPRESSION METHOD USING ICABASIS

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ABSTRACT

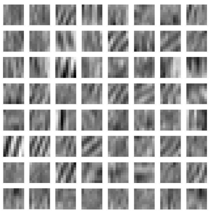
Since the bases set of Discrete Cosine Transform (DCT) in JPEG considers the statistical characteristics of the image, that is a problem that the quality of the encoded image deteriorates in the local features when the bit rates become lower. On the other hand, since the basis set of Independent Component Analysis (ICA) is corresponding to the structural features of a given input image, the hybrid image coding method is proposed for the purpose to take advantage of each strength of DCT and ICA. Image coding using ICA has a problem that the entropy for preserving the ICA bases increases because the sender and receiver need to share the ICA bases. In this paper, by selecting the combination of the proper ICA bases for improving the coding performance, the coding performance is improved from DCT even when the entropy of the ICA bases is added.

1. INTRODUCTION

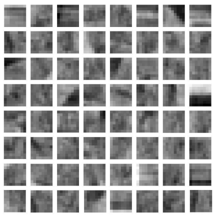
Discrete Cosine Transform (DCT), which has been adopted as a standard image coding method, is one of the effective methods based on orthogonal transform with energy compression. Since the identical DCT basis is applied to any input image, and the DCT coefficients are quantized based on human visual characteristics, it is effective in preserving areas that are satisfied with statistical characteristics. However, it is well known that at low bit rates, there are problems of visual distortions such as mosquito noise and block noise. On the other hand, independent component analysis (ICA), a form of multidimensional signal analysis, can obtain a set of bases corresponding to the structural features of a given input image, and by focusing on the sparsity of the ICA coefficients, the local features of the image can be preserved with only a few bases [1, 2]. Therefore, DCT and ICA have different features to preserve image singles.

A hybrid image coding method has been proposed, which uses both DCT and ICA bases to preserve of an input image efficiently by using ICA to preserve feature that are difficult to preserve with DCT [3, 4]. In [3, 4], the given input image is divided into small blocks and classified into two types of blocks which DCT is applied (DCT_Block) and blocks to which ICA is applied (ICA_Block). Since the obtained set of ICA basis is depends for each input image, it is supposed to be shared by the sender and receiver. In order to obtain the high image quality, it is need to use multiple types of the ICA bases, however, this is undesirable from the viewpoint of bit rates because it increases the information required to preserve the ICA bases. Therefore, [3, 4] reduce more than about 80% of the entropy to obtain the preserve equivalent image quality by selecting important the ICA basis that can improve the coding performance. In [4], they focus on the ICA bases that maximize the image quality in each block and determine the important bases combinations by evaluating the image quality that can be improved from DCT for each candidate for ICA_Block. Here, the candidates for ICA_Block are defined as a block that can improve the coding performance over DCT under the condition that all 64 ICA bases can be used. If all candidates of ICA_Block are used as ICA_Block, the entropy to preserve the ICA bases increases significantly, so it is only evaluated the validity of each ICA bases combination, and the proper ICA_Block is chosen from ICA_Block. However, the conventional method [4] has the coding performance deterioration when the entropy of the basis is added and bit rates at which the performance can be improved is in the impractical region where the PSNR is about 20[dB].

In this paper, we need to improve the algorithm of the hybrid-type image coding to practical bit rates. In term of improving the coding performance in each block, it is assumed that there are several effective bases other than optimize the image quality of the candidates of ICA_Block in the conventional method. Therefore, the proposed method determines the important ICA bases and ICA_Block that can improve the coding performance by including in the evaluation the basis that can improve the image quality even if the image quality of the block cannot be optimized. It is clarified in our proposed method that the problems of the conventional methods are solved, and the coding performance is improved over DCT at high bit rates with PSNR of 30~50[dB].



(a) “Barbara” (b) ICA basis of “Barbara”



(c) “Airplane” (d) ICA basis of “Airplane”

Figure1. Images and ICA basis

2. IMAGE CODING METHOD USING ICA

2.1. Independent Component Analysis

Independent component analysis (ICA) is a method of transforming observed multi-dimensional random vectors into original signals that are as independent as statistically possible. When the input signal $X = (x_1, x_2, \cdots, x_m)^T$ is represented by a linear combination of independent bases $S = (s_1, s_2, \cdots, s_n)^T$ can be written as

$$X = AS. \tag{1}$$

Note that A is the coupling coefficient represented as an $(m \times n)$ matrix, and element a_{ij} represents the contribution of the independent basis s_i to the input signal x_j. Since ICA does not have the information of the bases and coefficients, it must recover the basis S from the input signal X only. By denoting the inverse of A and the approximation of S as W and $Y = (y_1, y_2, \cdots, y_n)^T$ respectively, equation (1) can be transformed as

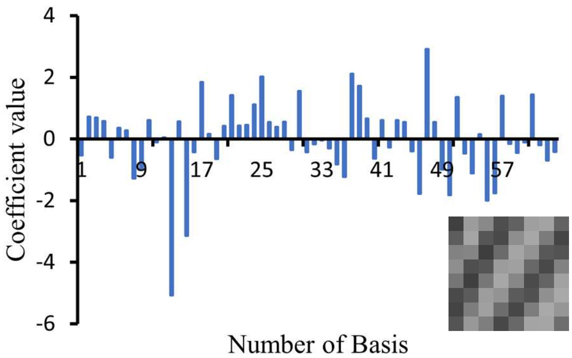
$$Y = WX. \tag{2}$$

In ICA, the objective is to find the ICA coefficients W that makes each component of the ICA bases Y independent. The Kullback-Leibler information content [5] is used as the evaluation criterion for independence, and by applying the method based on the steepest descent method [6] proposed by Bell et al, we can obtain an update rule for Y that minimizes the mutual information content,

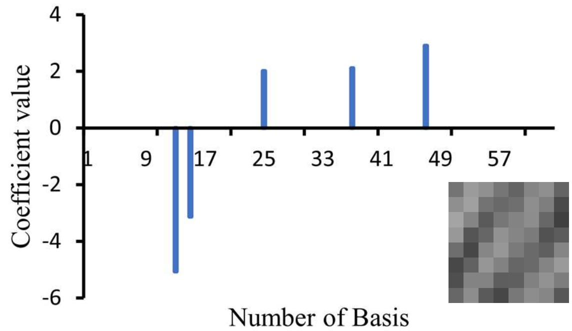
$$W^{k+1} = W^k + \mu[I - \varphi(Y)Y^T]W^T, \tag{3}$$

where μ is the learning coefficient, I is the unit matrix, and φ is an approximation of the probability density function of Y. Typically, the Sigmoid function is used as φ.

In this paper, the number of ICA bases is determined to 64 to match the (8×8) pixel DCT bases in the proposed method. Fig.1 shows the ICA bases derived by applying equation (3) when input images "Barbara" and "Airplane" is given. It is seen in Fig.1 that the ICA basis corresponds to the local features of each input image and the shape of bases is deferent from each input image. The ICA coefficients of an arbitrary block in the image "Barbara" are shown in Fig. 2(a). For the block in Fig. 2(a), the block reconstructed using only ICA basis with large coefficients values is shown in Fig. 2(b). It is seen in Fig. 2 that, the ICA coefficients have sparsity [7] since only a few ICA bases can preserve the local features of the input image. Therefore, it is expected that the ICA basis can reduce the entropy required to preserve the signal of blocks with local features compared to DCT.



(a) Reconstructed block with all ICA coefficients



(b) Reconstructed block with a part of ICA coefficients

Figure2. Sparseness of the ICA coefficients

2.2. Conventional Methods

As mentioned in Section 2.1, the signal of blocks with local features can be preserved with less entropy by using ICA because the ICA coefficients are sparse. On the other hand, stochastic regions can be preserved with less entropy using DCT because the ICA coefficients don’t satisfy the sparseness. Therefore, from the viewpoint of the entropy reduction, we can classify an input image into blocks that are predominantly preserved by DCT basis or ICA basis and encode each block using DCT and ICA to reduce the overall entropy of the image. In DCT, the entropy is controlled by using a quantization table for the DCT coefficients. On the other hand, to reduce the number of ICA bases from the viewpoint of the entropy to preserve the ICA basis, in [3, 4], the importance of each ICA bases to the preservation of the signal of block is determined by the similarity between the block and the basis based on the MP method [8], and

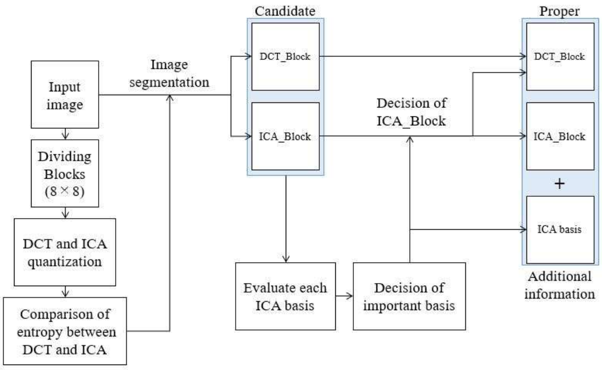


Figure3. Configuration of hybrid image coding using DCT and ICA basis

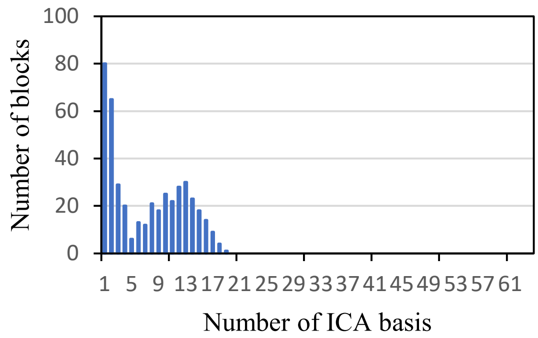


Figure4. Number of ICA basis for reconstruction in each block

the entropy is controlled by selecting the basis with the highest importance.

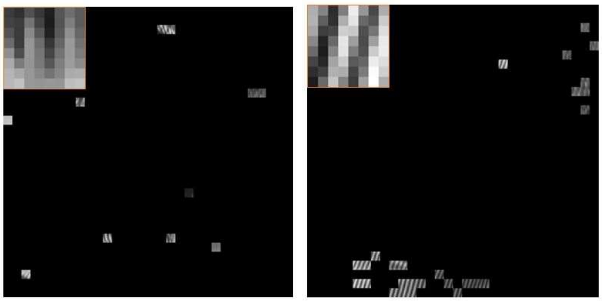
DCT and ICA are applied to each block under the condition of same MSE, and then the candidates of DCT_Block and ICA_Block are determined by comparing the entropy. The candidate of ICA_Block is defined as the blocks that requires less entropy than DCT under the condition that all of 64 ICA bases can be used. If candidates of ICA_Block are encoded as ICA_Block, the entropy to preserve the ICA basis increase significantly, so they are only used to evaluate each ICA basis combination, and the proper ICA_Block is determined from the candidates of ICA_Block. When the proper combination of the ICA bases is determined, the blocks to which they apply are defined as the ICA_Block, and the other blocks are the DCT_Block. In selecting the ICA bases, [3, 4] focus on the ICA bases that optimize the image quality of each block, and determine the important bases by evaluating the image quality that each basis can improve from DCT for each candidate of ICA_Block. In [3], it is shown that the hybrid type image coding can be reduced by more than 80% of the entropy of the ICA basis required to preserve image quality equivalent to that using DCT. Also, it has been in [4] shown that the entropy of the ICA bases is added the coding performance can improve over the DCT at very low bit rates when.

The conventional hybrid-type coding methods have the following problems. The first is that the proper bases have not been chosen for the quantization of ICA. Although the ICA coefficients are sparse, there are only a limited number of blocks for which use an only base can preserve the same image quality as DCT, so multiple bases are used in combination. Therefore, the importance of preserving the signal of the block should be considered when combining multiple types of ICA bases. The second is that in the selection of important ICA bases, there is other effective ICA bases besides the ones that optimize the block quality in terms of improving the coding performance. It has also been confirmed that there are blocks that can be reconstructed using only the average of the brightness values without using the ICA bases. Therefore, under the condition that the multiple ICA bases are used, the blocks that the candidates of ICA_Block and the bases in the conventional methods that were evaluated are not optimal for improving the coding performance. In addition, the range in which the conventional method can improve the coding performance is only at very low bit rates whose image quality is lower than 20[dB]. In sec.3, we propose a new method in ICA_Block to solve the above problems and improve the coding performance of hybrid-type coding algorithm using both DCT and ICA basis.

3. PROPOSED METHOD

The configuration of the proposed hybrid-type image coding method is shown in Fig. 3. In Fig. 3, we first divide the input image into uniform blocks of (8×8) pixels and then apply DCT and ICA to each block to obtain the DCT coefficients, the ICA coefficients respectively, and the ICA basis. In the proposed method, the DCT is quantized by a JPEG-based quantization table, and the ICA is quantized by reducing unnecessary basis to equal the quality of the DCT based on the MSE using MP method. In the block segmentation, first, both the entropy of DCT coefficients and ICA coefficients are calculated in each block. The entropy of DCT coefficients is calculated as the average information volume of DCT coefficients, and the entropy of ICA coefficients is calculated as the average information volume of the combined ICA coefficients and the average of the blocks of the brightness values. In next, all blocks of the input image are once classified as ICA_Block or DCT_Block by making them of the candidate for ICA_Block if the entropy of ICA coefficients is less than that of DCT coefficients, and making the others candidate of DCT_Block.

In the selection of the important ICA bases, we evaluate each ICA bases combination in terms of improving the coding performance for the candidates of ICA_Block. As mentioned in the previous section, all combinations of the ICA basis that can improve the block coding performance are included in this evaluation. Then, among the combinations of ICA bases that can be reduced to less than the entropy of DCT even when the entropy of preserving the ICA bases is added, that can maximize the image quality of the entire image is



(a)ICA base of No.23 (b)ICA base of No.40

Figure5. A set of blocks is applied to each ICA base

determined to be the important ICA bases, and the both blocks in which these bases are used and the blocks whose image quality can be improved by only the average of the brightness values are determined to be the proper ICA_ Block. After the ICA basis and ICA_Block are determined, and the DCT_Block excludes all the areas in the image to them, and then DCT and ICA are applied to each block for image coding.

3.1. Determination of the candidates of ICA_Block

Since the image quality evaluation is used by PSNR, the importance used in quantization is also based on MSE in the proposed method. Although the ICA coefficients are sparse, only few blocks can preserve image quality equivalent to DCT with unique ICA basis, and often multiple types of the ICA bases are combined to preserve the image quality. When the conventional method is applied to the image "Airplane" with PSNR=31[dB], the number of ICA bases that are required to preserve for the candidate of ICA_Block and the number of blocks that required them is shown in Fig.4. Fig.4 shows that although there are many blocks that can preserve image quality equivalent to DCT using unique ICA basis, there are more blocks that can preserve by combining multiple types of bases.

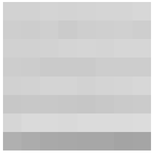
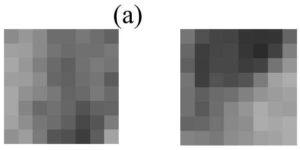
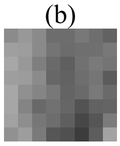
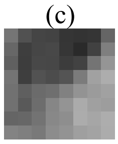
Therefore, we solve the problem in the quantization of ICA of the conventional method by proposing the importance of the bases that preserve the signal of blocks based on the MSE when the combination of ICA bases is considered. For each block in the input image, we find the ICA basis $I_i (i = 1,2,\cdots,64)$ that minimizes the MSE and make I_i the most important basis for that block. Then, the other ICA basis $I_n (n = 1,2,\cdots,64$, where $n \neq i)$ that can minimize the MSE when combined with I_i is the second most important basis for that block. This process is continued until the importance is determined for 64 ICA bases, and the importance order of the basis is obtained for all blocks. The image quality and entropy improved from the DCT when the image quality is controlled by the importance which is mentioned the above are obtained using Equation (4) and Equation (5).

$$DCT_Q - ICA_Q\{a_i\} \quad (4)$$

$$DCT_e - ICA_e\{a_i\} \quad (5)$$

Here, DCT_Q is the DCT and $ICA_Q\{a_i\}$ is the mean square error (MSE) with the original image when the block is reconstructed using ICA bases of $i (i = 0,1,2,3)$ according to importance order, in addition DCT_e denotes DCT and $ICA_e\{a_i\}$ denotes the entropy by summing the information of the coefficients and the information of the average of the brightness values in the blocks when the block is reconstructed using ICA bases of $i (i = 0,1,2,3)$. The blocks for which equations (4) and (5) are positive, i.e., the blocks with higher image quality and less the entropy than DCT, are candidates of ICA_Block, and the other blocks are candidates of DCT_Block.

Table1. ICA basis combinations effective for block preservation

	Effective ICA basis for block of No.1000
 Block of No.1000	(a)  ICA base of No.39 and No.59
	(b)  ICA base of No.39
	(c)  ICA base of No.59

3.2. Determination of Important ICA basis

In the proposed method, 64 ICA bases are calculated for a given image. Since they are specific to the image and each basis represents the local features, the type of the ICA bases that is effective in improving the coding performance are different from each block. We applied the quantization of the proposed method to the image "Barbara" with PSNR=30[dB], and among classified to the candidates of ICA_Block, the blocks optimizing by the 23rd and 40th ICA basis are shown in Fig. 5. The shape of the ICA basis is shown in the upper left corner of Fig. 5. In Fig. 5, we can see that each ICA basis is used in the different blocks.

However, if we consider the preservation of the signal of a block by the combination of multiple ICA bases, there are multiple combinations of bases that can improve the coding performance. Table.1 shows combinations of the ICA bases that can improve the coding performance over DCT when preserving the signals of the 1000th block for the image "Airplane" with PSNR=25[dB]. Table.1 shows that there are multiple combinations of the ICA bases that are effective in preserving the signal of this block. In the conventional method, since only the ICA basis that can maximize the

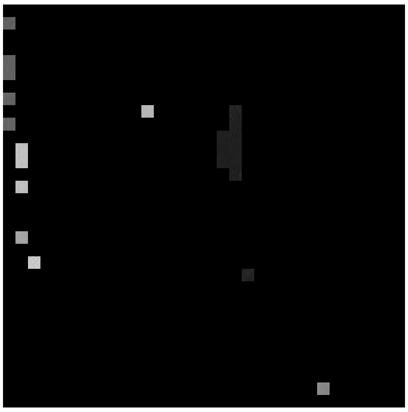


Figure6. A set of blocks is reconstructed by only DC component in ICA

image quality of the block is evaluated that is Table.1(a) as the basis that can improve the coding performance of this block, while the bases of Table.1(b) and (c) are excluded.

In the proposed method, by including all of combinations of the ICA basis in the evaluation, we can properly evaluate the importance of each combination of the ICA basis for the preservation of the candidates of ICA_Block. Since it has been already shown from [3, 4] that the coding performance can be improved even when the entropy of about two ICA bases is added at low bit rates, we decided to use up to three bases in the proposed method. In addition, although the ICA_Block of the conventional method always requires the use of the ICA basis, it is confirmed that some the blocks can preserve higher image quality than DCT by simply using the average of the brightness value without using the ICA bases. Fig. 6 shows the blocks that preserves higher image quality than DCT without using ICA basis when ICA is applied to the image "Barbara" under the condition of PSNR=30[dB]. Fig. 6 shows that some blocks can be reconstructed using only the average of the brightness values even at the practical bit rates of PSNR=30[dB]. When preserving blocks with only the average of the brightness values, since it need not the entropy to preserve the ICA coefficients and the ICA basis, it is very effective in terms of performance improvement.

Selecting method of the optimal ICA basis is described as follows. First, the image quality improvement $Q\{a_i\}$ and the reduction bit rates $e\{a_i\}$ for each $\{a_i\}$, which is the sum of the improvement values calculated from equations (4) and (5), are obtained using

$$Q\{a_i\} = \sum_{ICA\_Block} DCT_Q - ICA_Q\{a_i\} \qquad (6)$$

and

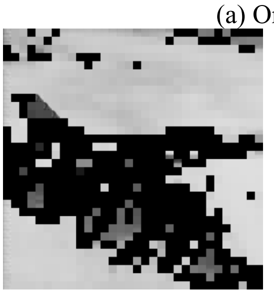
$$e\{a_i\} = \sum_{ICA\_Block} DCT_e - ICA_e\{a_i\}. \qquad (7)$$

The ICA_Block in equations (6) and (7) corresponds to the candidate of the ICA_Block computed earlier, excluding the blocks that do not need the basis in Figure 6. The above process determines both the entropy that can be reduced and the image quality that can be improved from DCT for all the combinations of the ICA bases. As the result, since it can evaluate the improvement in coding performance in consideration of the entropy for the ICA basis added, we can compare the entropy required to preserve the basis and the entropy that can be reduced from DCT for each combination of the ICA basis. Since the entropy of the image coding using ICA is calculated by adding the entropy of the ICA basis to the ICA coefficients and the average of the brightness values of each block, the coding performance may deteriorate than that of DCT that does not need the entropy of the basis. Therefore, the basis selection method must be evaluated that the coding performance improve considering the entropy of the ICA basis. When the entropy to preserve the signal of block shown in Figure 6 is ICA_e, $e\{a_i\}$, which satisfies equation (8) and maximizes $Q\{a_i\}$ of equation (6), is selected as the ICA basis important for preserving the input image, and the ICA_Block using $\{a_i\}$ is determined as the proper ICA_Block in the image.

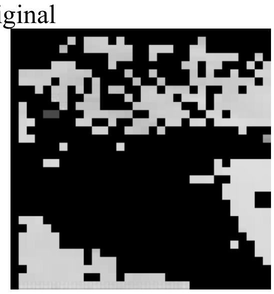
$$\sum_{ICA\_Block} DCT_e - ICA_e + e\{a_i\} > ICA_{Basi\ e\{a_i\}} \qquad (8)$$

$ICA\_Basis_e\{a_i\}$ is the entropy to preserve the basis of $\{a_i\}$, and equation (8) implies that even with the addition of the entropy to preserve the ICA basis, the overall

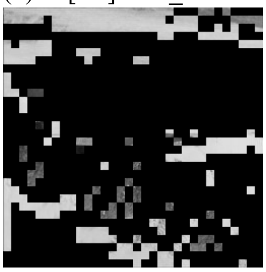
(a) Original



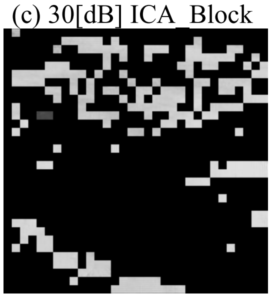
(b) 25[dB] ICA_Block



(c) 30[dB] ICA_Block

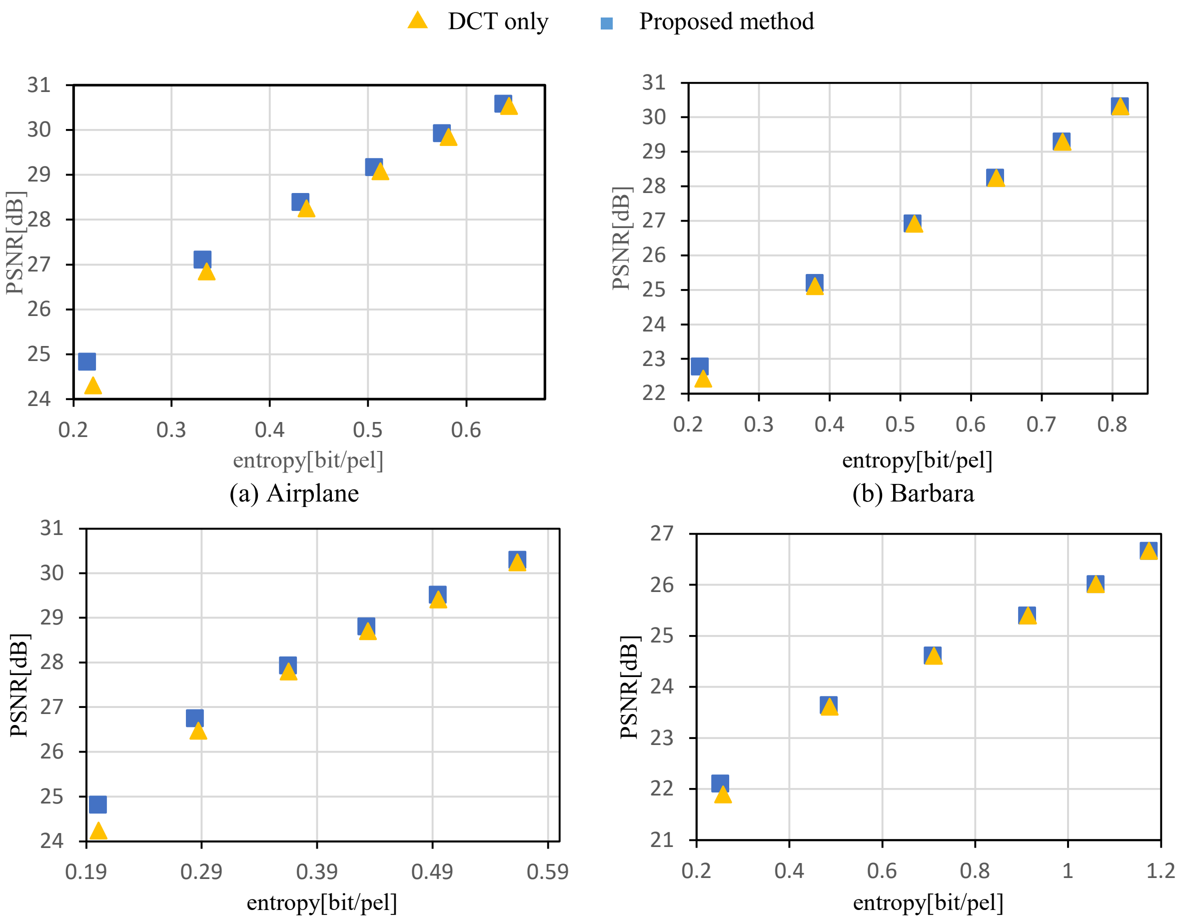


(d) 25[dB] Conventional



(e) 30[dB] Conventional

Figure7. Proper ICA_Block compared with conventional method



(a) Airplane (b) Barbara

(c) Cameraman (d) Mandrill

Figure8. Coding performance of proposed method compared with DCT

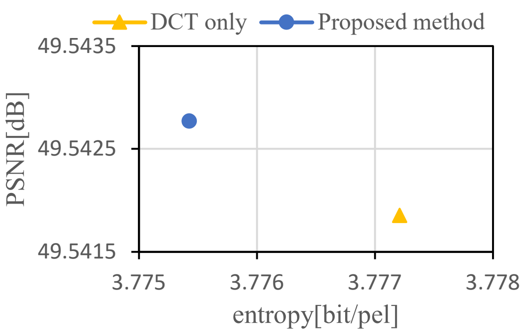


Figure9. Coding performance at the case of low compression

entropy will be less than DCT. The above process can be applied to determine the combination of the ICA bases that can optimize the overall image quality and the ICA_Block, considering the entropy of the ICA basis.

4. EXPERIMENTAL RESULTS

The proper ICA_Block under the conditions of PSNR=30[dB] and 25[dB], obtained by applying the proposed method to the image "Airplane", are shown in Fig. 7. Fig. 7 compares the proper ICA_Block of the proposed method and the conventional method, where the ICA_Block is shown in the original image and the DCT_Block is shown in black. Fig.7(b) and (c) show that the ICA_Block differs depending on the bit rates. Fig.7(b), (c), (d), and (e) show that the ICA_Block of the proposed method is more than the conventional method, which is since the proposed method considers the combinations of ICA bases. Since the combination of each ICA basis changes according to the candidates of ICA_Block, the ICA basis selected for each bit rate will also be different in the proposed method.

Next, we apply the proposed method to the 256×256 pixel images "Airplane", "Barbara", "Cameraman", and "Mandrill" and the PSNR vs. entropy results of the proposed method are shown in Fig. 8. In Fig. 8, the results of DCT and the proposed method are compared. An increase in ICA_Block means that more blocks can be preserved with less entropy than DCT at the same PSNR, which is expected to improve coding performance. Fig.8 shows that the coding performance of the proposed method is better than that of DCT. In PSNR=30[dB], which is a practical bit rate, the proposed method can save on average 0.0025[bit/pel] less than the entropy of DCT. Note that the entropy of the proposed method is the sum of the entropy for the ICA coefficients, the entropy for preserving the average of the brightness values of the ICA_Block, and the entropy for preserving the ICA bases. We also found that at lower bit rates, around PSNR=25[dB], we can save up to 0.03[bit/pel] of the entropy. The result of applying the proposed method to the image "Airplane" under the conditions of PSNR=50[dB] is shown in Fig. 9. Fig.9 shows that the coding performance of the proposed method is better than that of DCT. From the above, it has come the proposed method can improve the coding performance from that of DCT in practical bit rates.

5. CONCLUSION

In this paper, we proposed the ICA bases selection method to improve the performance of the hybrid image coding method using ICA and DCT. The proposed method divides the input image into 8×8 blocks and classifies them into two types: blocks to which DCT is applied (DCT_Block) and blocks to which ICA is applied (ICA_Block). Image coding using ICA has a problem that the entropy for preserving the ICA bases increases because the sender and receiver need to share the ICA bases. To solve these problems, each combination of the ICA bases was evaluated in terms of image quality, and the entropy that each combination of the ICA bases can reduce and the entropy need to preserve the ICA bases were compared to determine the combination of the optimal ICA bases and the proper ICA_Block. As the result, the proposed method is improved to the coding performance in the range of 30~50[dB] PSNR even when the entropy to preserve the ICA bases is added.

In the proposed method, the combination of the ICA basis and ICA_Block used in the ICA_Block differs depending on the bit rates, so the processing for each bit rates is necessary, and the reduction of the processing cost of the proposed method is left by the future problem.

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