Optimaization of The Bases to Use and The Blocks to Apply in DCT-ICA Hybrid Coding Methods

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*Abstract*— The Discrete Cosine Transform (DCT) used in JPEG can extract and store the statistical features required by the image using a general-purpose basis, but it does not consider human vision because visual distortion becomes a problem at lower bit rates. Therefore, The DCT-ICA hybrid method has been proposed to preserve features needed by both images and human visuals by combining them with independent component analysis (ICA), which can extract and preserve the features handled by human vision. When DCT and ICA are combined, it is necessary to optimize the application area of the ICA basis, and there is also the entropy increase due to additional information. In this paper, we show that by solving them, the proposed method can improve the coding performance from DCT at reasonable bit rates of 30-50[dB].

Keywords—image compression, lossy compression, discrete cosine transform, independent component analysis.

# Introduction

The discrete cosine transform (DCT) used in international image coding methods such as JPEG is one of the effective methods based on the orthogonal transform with energy compression [1]. The same DCT basis is applied to any image, and high-frequency information is removed by the Q table. Therefore, it is effective in preserving areas with the statistical features needed by the image. However, visual distortions such as mosquito noise and block noise are known to be problems at low bit rates. Noise is considered to occur because of the lack of visually necessary information, and DCT is considered to remove information that is necessary for humans. On the other hand, sparse coding, which models the human early visual system, can preserve features within a block with only a few bases by focusing on the sparsity of the coefficients [2,3]. It has been suggested that by applying independent component analysis (ICA), a member of the sparse coding family, to images, it is possible to obtain basis functions similar to Gabor functions and thus extract features handled by human vision [4,5]. Therefore, DCT and ICA extract different features from the image. Therefore, DCT-ICA hybrid coding methods have been proposed to preserve information needed by both images and humans by using ICA to preserve information needed by human vision, which cannot be preserved by DCT [6~8]. To use DCT and ICA together, it is necessary to optimize the application area and the basis used when ICA is applied. Since the basis sets obtained by ICA are different for each input image, it is assumed that they will be shared by the encoder and decoder. Therefore, there remains the problem of coding performance deterioration due to additional information for sharing the ICA basis. In [6,7], those problems were solved, but there are still problems, such as the unreasonable bit rates at which coding performance can be improved and the lack of appropriate entropy comparisons.

In this paper, we analyze the problems of conventional methods and propose a more suitable process to solve the DCT-ICA hybrid method modification.

# IMAGE CODING METHOD USING

## Independent Component Analysis (ICA)

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 is represented by a linear combination of independent bases can be written as

Note that is the coupling coefficient represented as an matrix, and element  represents the contribution of the independent basis to the input signal. Since ICA does not have the information of the bases and coefficients, it must recover the basis from the input signal only. By denoting the inverse of and the approximation of as and respectively, (1) can be transformed as

In ICA, the objective is to find the ICA coefficients that makes each component of the ICA bases independent. The Kullback-Leibler information content [9] is used as the assession criterion for independence, and by applying the method based on the steepest descent method proposed by Bell et al., we can obtain an update rule for that minimizes the mutual information content,

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

In this paper, the number of ICA bases is determined to 64 to match the 8 × 8 pixels DCT bases in the proposed method. Fig.1 shows the ICA bases derived by applying (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. Fig.2 shows the reconstructed block with all ICA coefficients and the block reconstructed with a few ICA coefficients with large coefficient values. It is seen in Fig. 2 that, the ICA coefficients have sparsity [2~4] 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.

## Problems of Conventional DCT-ICA Hybrid Methods

From Fig.2, the signals of blocks with local features have sparse ICA coefficients, and thus the application of ICA is expected to reduce entropy. On the other hand, areas with flat or regular features are more effective to have DCT applied because the ICA coefficients do not satisfy the sparsity. Therefore, the entropy of the overall image can be reduced by preserving each block of the input image with DCT or ICA. Since the DCT and ICA coding processes cannot be used together in a single block, it is necessary to classify each block in the image as to whether DCT or ICA should be applied. ICA quantization is not a quantization method that controls image quality in a standard way, such as Q-table, but rather a method that reduces entropy by selecting the optimal ICA coefficients for the bit rate of interest and setting all other coefficients to 0. Since the number of bases used in each block in hybrid coding methods refers to DCT coding, the ICA coefficients to be chosen must be optimized. Since the ICA basis obtained by ICA are different for each input image, it is supposed to be shared between the encoder and decoder. The additional information to be shared increases in proportion to the type of ICA base used in the overall image. If the two optimizations are performed without considering this, there will be more additional information on the ICA basis, which will degrade coding performance. Therefore, in addition to the two optimizations, it is necessary to limit the number of ICA basis types used in the overall image to a small number.

[6,7] determines the priority for choosing coefficients according to the similarity between the block and the ICA base based on the MP method [10]. It also addresses problems in the application area by assessing the image quality that each ICA base set can improve. The results show that the entropy of the ICA basis required for image quality equivalent to DCT can be reduced by more than 80% [6]. It has also been shown that coding performance can be improved at quite low bit rates of around 20 dB, consider additional information [7]. However, problems remain with these conventional hybrid coding methods. Since there are only a limited number of blocks in ICA quantization where a single coefficient can maintain the same image quality as a DCT, multiple coefficients must be retained. The priority obtained by the MP method is not appropriate because it does not consider the combinations between bases. There are also other efficient bases besides the ICA basis that can optimize the image quality of a block [8]. In the next section, we propose a new method to solve the above problems and improve the coding performance of DCT-ICA hybrid coding at reasonable bit rates.

# PROPOSED METHOD

The configuration of the proposed DCT-ICA hybrid coding method is shown in Fig.3. In Fig.3, we first divide the input image into uniform blocks of 8 × 8 pixels and apply DCT and ICA to each block to obtain the DCT and ICA coefficients, respectively, and the ICA basis. In the proposed method, DCT is quantized by the Q table of JPEG, and ICA is quantized by the reduction of unnecessary coefficients to be equivalent to the quality of DCT by the proposed priority. The above process degrades coding performance due to a lot of additional information because it increases the number of ICA basis types used in the overall image, as mentioned in the previous section. Assessment each ICA base set to limit the types of ICA bases used in the overall image. The combined entropy of the overall image and the additional information to preserve the ICA basis are then compared to the entropy of the DCT.

## Priority for Coefficients Choise

Since image quality assessment is based on PSNR and SSIM, the priority for choosing coefficients is also based on MSE. ICA coefficients are sparse, but to preserve image quality, several ICA bases are most often used simultaneously [8]. Although the exhaustive search is appropriate for choosing the proper coefficients for block preservation, it is unreasonable to apply it to all blocks due to a lot of computation complexity. Therefore, we solve the problem of priority for coefficient choice by proposing a method that can obtain a priority equivalent to an exhaustive search with a few computational complexity. For each block in the input image, we find an ICA base that minimizes the MSE and makes the most preferentially chosen base in the block. is the priority of coefficients to be chosen in the block and the corresponding ICA base is used. is most likely to be chosen and is least likely to be chosen. Then, under the condition that is used, the other ICA base ( where ) that can minimize the MSE when used together is for that block. This process continues until is determined, and the priority for selecting coefficients is obtained for all blocks. This allows the appropriate ICA coefficients to be chosen with little computational complexity when the number of bases used in a block in DCT coding has been determined.

To verify the effectiveness of the proposed method, we obtain the MSE when the proposed coefficients are chosen, the MSE when the conventional coefficients are chosen, and the MSE when the coefficients are chosen in exhaustive searches. Here, MSE is based on the original image. The image quality loss of the proposed method compared to the exhaustive search in Table Ⅰ. Table Ⅰ shows how much image quality is lost when one to three coefficients are chosen, compared to the exhaustive search. The values in Table Ⅰ are the error from the MSE of the exhaustive search, with positive values representing degradation from the exhaustive search. The conventional method has significantly degraded image quality compared to the exhaustive search. In contrast, the proposed method shows almost the same image quality as the exhaustive search. The above allows the proposed priority to choose more appropriate coefficients than conventional methods.

## Assessment of Each ICA Base Set

By assessing the ICA basis in this section, we limit the number of ICA basis types used in the overall image to a few, thereby suppressing the overall entropy of the combined additional information. At low bit rates, combining about two ICA bases of entropy has been shown to improve coding performance [6,7]. Therefore, the proposed method uses up to three ICA bases at all bit rates. If the improvement in image quality of a block due to is

the improvement in image quality of the overall image due to is

Where is the original block, is the reconstruction of a block by DCT, is the reconstruction of a block by , and is the block size, is the number of blocks in the overall image. Since ICA is not applied to blocks whose image quality is reduced by , we focus only on blocks whose image quality is improved. The above process allows the choice of the bases that maximize image quality even when the number of ICA basis types used in the overall image is restricted.

## Determing ICA Bases to Use and the Blocks to Apply

Since the ICA basis is assumed to be shared by the encoder and decoder as mentioned in the previous section, the combined entropy of the ICA coefficients and additional information is obtained. The entropy of the proposed method is obtained by the average information content

Where Ω is the set of coefficient values for the entire image, A is the coefficient, and P(A) is the probability of A. The proposed method obtains the combined entropy of the coefficients and the entropy of the additional information and compares it with the entropy of the DCT.

Where is the entropy of the additional information combined, is the entropy of the coefficients, is the entropy for sharing the ICA basis,

is the number of pixels in the input image, and is the number of pixels in the ICA basis. The entropy is compared in order from the one that can improve the image quality the most in the obtained in the previous section, and the one that is below the entropy of the DCT first is decided as the bases to be finally used. The block to which they are applied is also determined to be the final block to be applied.

# EXPREMENTAL RESULTS

## PSNR vs. Entropy and SSIM vs. Entropy

The PSNR vs. entropy of the proposed method applied to the 256 256 pixels images "Airplane", "Barbara", "Cameraman", and "Mandrill" is shown in Fig.4. SSIM vs. entropy is also shown in Fig.5. Compare the results of DCT and the proposed method in Fig.4 and 5. The high bit rates show a lot of entropy reduction, while the low bit rates show better image quality in Fig.4 and 5. This result is a specialty of the proposed method because it reflects the ICA characteristic of being able to preserve image quality with little entropy. The proposed method can reduce entropy by as much as 0.08 [pit/pel] and improve PSNR by as much as 0.1 [dB] at reasonable bit rates from 30 to 50 [dB].

## The ICA Bases Used and The Block Applied for Each Bit Rate

The ICA bases and their application blocks obtained by applying the proposed method to the image "airplane" are shown in Fig.6. The ICA applied block in the original image and the DCT applying block in black in Fig.6. Three ICA bases are used at reasonable bit rates in Fig. 6. This result is the maximum in the proposed method and is because the proposed method reduces a lot of entropy. Further improvement in coding performance is expected because it is thought that more than four ICA bases can be used in the future.

# CONCLUSION

The DCT-ICA hybrid coding method has the advantage of preserving both the image and the information needed by human vision, but it was necessary to optimize the ICA basis used and the blocks to which it is applied and to solve the problem of additional information to share the ICA basis. To solve this problem, we proposed a process that is comparable to an exhaustive search for priorities for choosing the coefficients of a block. The entropy of the shared ICA basis was reduced by limiting the number of ICA basis types used in the overall image to a maximum of three and comparing the image quality obtained for all patterns. Furthermore, by comparing the combined entropy of the additional information in order from the pattern that can maximize the image quality, we were able to reduce entropy from DCT and determine the ICA basis that can maximize the image quality. As a result of the proposed method, the coding performance can be improved from DCT even when the additional information is combined, and the problems of conventional DCT-ICA hybrid coding methods are solved.

Since the ICA basis used for each bit rate is different in fig.6, the features focused on are likely to be different. Therefore, our future work is to clarify the features that ICA focuses on for each bit rate.

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