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Fast Lossless JPEG Image Geometric Transformation by DCT Coefficient Changes

Kang Yi[1], Jeong-Hyun Joo[2] and Kyungmi Kim[3]

[1] School of CS. & EE, Handong Global University, Pohang, Korea
[2]Department of Computer Engineering, Seoul National University, Seoul, Korea
[3] School of Global Leadership, Handong Global University, Pohang, Korea
yk@handong.edu, koo221@naver.com, kmkim@handong.edu

Abstract

Geometric transformations such as rotation or mirroring of JPEG images may result in image quality distortion. Our experiments found further quality degradation of rotated JPEG images as the number of rotations increases. In this paper, we propose a fast and lossless JPEG image transformation in spatial domain based on changes of discrete cosine transform (DCT) coefficient in frequency domain. The key idea of our proposed approach is that permutation and/or sign changes of DCT coefficients in JPEG image results in geometric change without any information loss. Our experiments shows that the proposed transformation algorithm results in no information loss and is faster than conventional methods by 1.67 times on average.

***Keywords**: Lossless JPEG transformation; transformation with DCT coefficients; fast image rotation; image quality distortion*

1. Introduction

Image data are mostly stored in a compressed form in local computer storages or cloud storages. With the wide spread of high quality image capturing consumer electronic devices such as sports action cameras, home security cameras, and personal life-logging cameras, the image processing demand is rapidly increasing. Thus, image related researches including image search, retrieval, transformation, and compression are becoming more important [1-5].

Depending on applications, stored images may have to be retrieved, edited or transformed, and restored after recompression. We observed noticeable image quality loss after image rotation due to recompression. The procedure shown in Figure 1 is to measure the JPEG image distortion by a series of decompression, rotation by 90° clockwise (CW), and recompression. For each iteration of the preliminary experiments in Figure 1, we compared the n^{th} rotated compressed image with rotated bitmap of the original image. With just four consecutive 90° clockwise rotations, we found the peak signal-to-noise (PSNR)has dropped by 2.07 dB on average. Note that in order to rotate the compressed images, the uncompressing process should be performed to get the bitmap image before rotation. Figure 2 illustrates the quality loss measured by the procedure in Figure 1, we measured the image quality differences in terms of both PSNR and structural similarity (SSIM). The Figure 1 shows that both the PSNR and SSIM decrease as the number of rotation of image increases which means the objective image quality as well as perceptual quality is seriously degraded with geometric transformation for compressed images. We found the quality loss saturates around 15.2 dB in PSNR and 0.82 in SSIM, which means unacceptable visual quality for commercial purposes.

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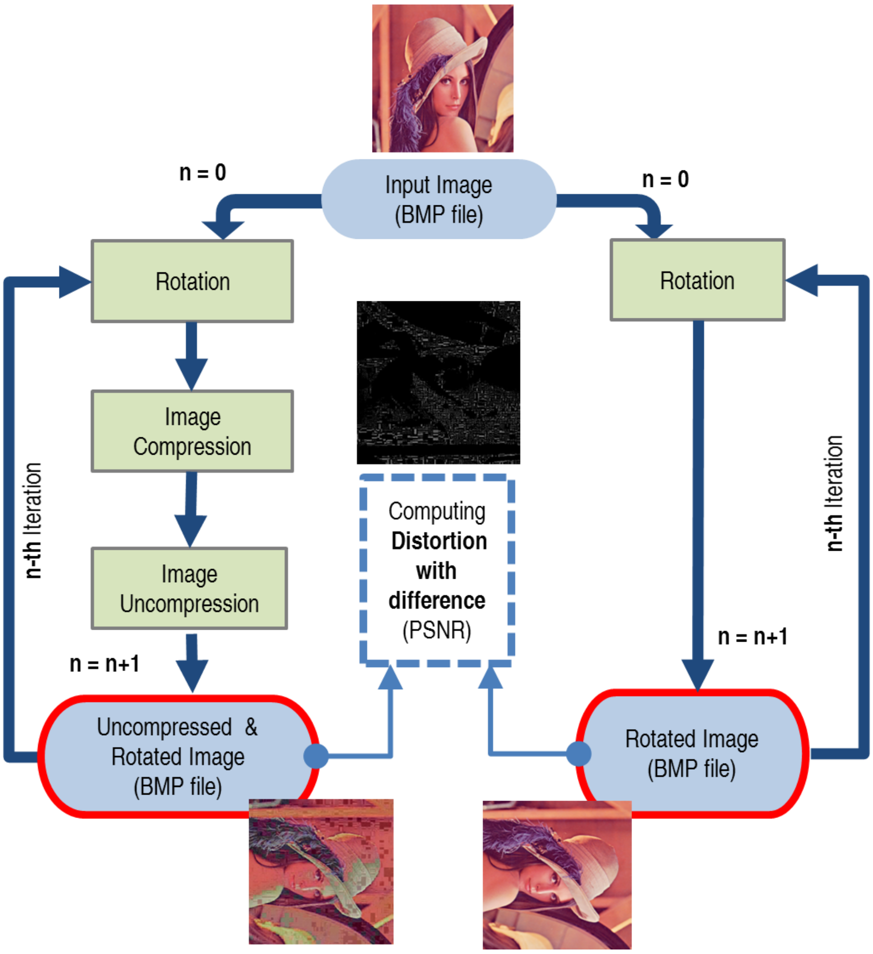

Figure 1. An Experimental Procedure to test Rotation Distortion of Compressed Image

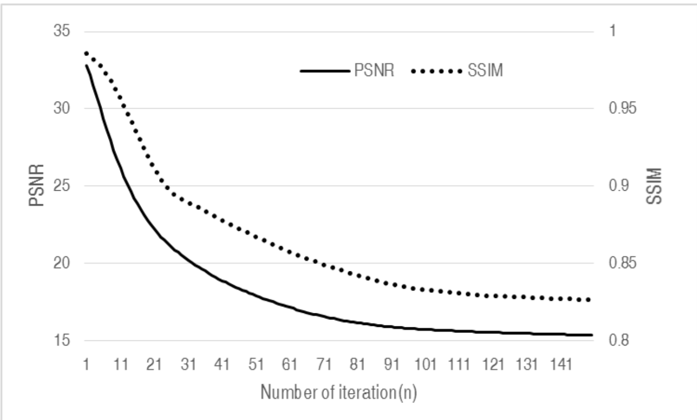

Figure 2. The Quality Degradation of JPEG Image by Conventional Rotation Method

With the conventional geometric transformation method that operates in pixel domain of image, compressed JPEG image quality distortion occurs due to the accumulated information loss in the process of real to integer number conversions during the decompression and/or compression processes including quantization/de-quantization, subsampling, and color space conversion. Furthermore, in case of geometric transformation such as rotation and mirroring, the asymmetric characteristics of default quantization table for JPEG as shown in (1) makes the distortion worse. Note that for each different orientation of image, multipliers/dividers used in de-quantization/quantization process differ quite much even with the same DCT coefficients, which results in further distortion by rotation or mirroring of JPEG images.

$$QP = \begin{bmatrix} 16 & 11 & \cdots & 51 & 61 \\ 12 & 12 & \cdots & 60 & 55 \\ \vdots & & \ddots & \vdots & \\ 49 & 64 & \cdots & 120 & 101 \\ 72 & 92 & \cdots & 103 & 99 \end{bmatrix} \quad (1)$$

There are a few previous works to rotate images in a lossless way based on a lapped orthogonal transform [6, 7]. Especially regarding the lossless rotation of JPEG images, a software has been developed utilizing the fact that each DCT block can be independently treated and untouched DCT block need not be recompressed [8]. And one patent claims rotating independent blocks and reordering the rotated blocks should result in a whole image rotation [9].

In this paper, we present a new transformation algorithm for JPEG images in order to overcome the image quality distortion problem incurred with transforming compressed images. We have found simple operations on DCT coefficients such as sign changes or location permutations results in geometric changes, thus our transformation does not lose any information. Furthermore, applying this method requires only the partial decoding of JPEG images, and we can reduce computing time significantly compared to the conventional method that fully decompresses and recompresses the images.

2. Proposed Lossless Image Transformation

Our proposed lossless JPEG transformation method consists of two steps: (i) intra-block rotation step that performs local transformation in each 8x8 JPEG DCT blocking frequency domain and (ii) inter-block relocation step that rearrange the DCT blocks in the whole image to complete the desired transformation in spatial domain. In the following sections, we explain the two step one by one.

2.1. Intra-Block Rotation by DCT Coefficient Change

The JPEG compression procedure comprises of the following steps: (i) color space conversion and subsampling, (ii) transforming image into by DCT, (iii) quantization of the DCT coefficients, and (iv) Huffman encoding.

The input image is divided into many 8 x 8 pixel matrix A=$\{a_{i,j}\}_{8\times8}$in this step (ii) and each A is transformed into frequency-coefficient matrix $\hat{A} = \{\hat{a}_{i,j}\}_{8\times8}$in the next step (iii) by DCT. Each $\hat{A}$ can be obtained from A and DCT matrix C=$\{c_{i,j}\}_{8\times8}$by the equation shown in (2)

$$\hat{A} = CAC^T$$

$$\text{where} \quad c_{i,j} = \begin{cases} \frac{\sqrt{2}}{4}, & i = 0 \\ \frac{1}{2}\cos\frac{\pi i}{16}(2j+1), 1 \le i \le 7, 0 \le j \le 7 \end{cases} \quad (2)$$

The DCT matrix C has the useful property shown in (3), where I represents identity matrix and CT is the transpose matrix of C.

$$C^T C = CC^T = I \tag{3}$$

We define matrix $A' = \{a'_{i,j}\}_{8\times 8}$ and $\widehat{A}' = \{\hat{a}'_{i,j}\}_{8\times 8}$ to represent transformed pixel matrix and its corresponding DCT coefficients matrix, respectively. In order to mathematically deduce $\widehat{A}'$ from $\widehat{A}$ for each transformation we need to define a matrix H, which has the property shown in (4).

$$H = \begin{bmatrix} 0 & 0 & \cdots & 0 & 1 \\ 0 & 0 & \cdots & 1 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 1 & \cdots & 0 & 0 \\ 1 & 0 & \cdots & 0 & 0 \end{bmatrix}, \quad \widehat{H} = CHC^T = \begin{bmatrix} 1 & 0 & \cdots & 0 & 0 \\ 0 & -1 & \cdots & 0 & 0 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 0 & 0 & \cdots & 1 & 0 \\ 0 & 0 & \cdots & 0 & -1 \end{bmatrix} \tag{4}$$

The pixel matrix A', obtained by 90°CW rotation of A, can be represented as (5) which means $a'_{i,j}(90°\text{CW}) = a_{7-j,i}$. This implies the relationship between $\widehat{A}$ and $\hat{A}'$ as shown in (6).

$$A'(90°\text{CW}) = A^T H \tag{5}$$

$$\hat{A}'(90°\text{CW}) = CA'C^T = CA^T HC^T = (CAC^T)^T (CHC^T) = \hat{A}^T \widehat{H} \tag{6}$$

The formula (6) shows that the DCT representation of 90° CW rotation in a spatial domain can be obtained by DCT coefficient changes without any need to decompress the JPEG image, as summarized in (7).

$$\hat{a}'_{i,j}(90°\text{CW}) = \begin{cases} -\hat{a}_{j,i}, & j \in \{1,3,5,7\} \\ \hat{a}_{j,i}, & otherwise \end{cases} \tag{7}$$

The pixel matrix A', obtained by 90° counter clockwise (CCW) rotation of A, can be represented as (8) from the fact $a'_{i,j}(90°\text{CCW}) = a_{j,7-i}$ and we can derive a DCT domain representation for A' as shown in (9).

$$A'(90°\text{CCW}) = HA^T \tag{8}$$

$$\hat{A}'(90°\text{CCW}) = CA'C^T = CHA^T C^T = (CHC^T)\ \ (CAC^T)^T = \widehat{H}\hat{A}^T \tag{9}$$

Similarly, The pixel matrix A', obtained by 180° rotation of A, can be represented as (10) from the fact the fact $a'_{i,j}(180°) = a_{7-j,7-i}$ and the DCT domain representation for A' can be derived as shown in (11).

$$A'(180°) = HAH \tag{10}$$

$$\hat{A}'(180°) = CA'C^T = CHAHC^T = (\mathrm{CHC^T})(\mathrm{CAC^T})(\mathrm{CHC^T}) = \widehat{\mathrm{H}}\widehat{\mathrm{A}}\widehat{\mathrm{H}} \tag{11}$$

From (10) and (11), the DCT coefficients for90°CCW ($\hat{a}'_{i,j}(90°\mathrm{CCW})$) and 180° rotation ($\hat{a}'_{i,j}(180°)$) can be obtained from DCT coefficients of JPEG ($\hat{a}_{j,i}$) as shown in (12) and (13) respectively.

$$\hat{a}'_{i,j}(90°\mathrm{CCW}) = \begin{cases} -\hat{a}_{j,i}, & i \in \{1,3,5,7\} \\ \hat{a}_{j,i}, & otherwise \end{cases} \tag{12}$$

$$\hat{a}'_{i,j}(180°) = \begin{cases} -\hat{a}_{i,j}, & [i \in \{1,3,5,7\} and j \in \{0,2,4,6\}] \ or \\ & [j \in \{1,3,5,7\} and i \in \{0,2,4,6\}] \\ \hat{a}_{i,j}, & otherwise \end{cases} \tag{13}$$

The pixel matrix A' of the horizontal mirroring of A can be obtained from from the fact $a'_{i,j} = a_{7-i,j}$ as shown (14) and we can derive the DCT domain representation as shown in (15).

$$A'(\text{H-mirroring}) = HA \tag{14}$$

$$\hat{A}'(\text{H-mirroring}) = CA'C^T = CHAC^T = (\mathrm{CHC^T})(\mathrm{CAC^T}) = \hat{H}\hat{A} \tag{15}$$

The pixel matrix A' of the vertical mirroring of A can be obtained from the fact $a'_{i,j} = a_{i,7-j}$ as shown (16) and we can derive the DCT domain representation as shown in (17).

$$A'(\text{V-mirroring}) = AH \tag{16}$$

$$\hat{A}'(\text{V-mirroring}) = \mathrm{CAHC^T} = (\mathrm{CAC^T})(\mathrm{CHC^T}) = \hat{\mathrm{A}}\hat{\mathrm{H}} \tag{17}$$

The vertical mirroring can be obtained in similar ways resulting in formula as shown (16) and (17).

$$\hat{a}'_{i,j}(\text{H-mirroring}) = \begin{cases} -\hat{a}_{i,j}, & j \in \{1,3,5,7\} \\ \hat{a}_{i,j}, & otherwise \end{cases} \tag{18}$$

$$\hat{a}'_{i,j}(\text{V-mirroring}) = \begin{cases} -\hat{a}_{i,j}, & i \in \{1,3,5,7\} \\ \hat{a}_{i,j}, & otherwise \end{cases} \tag{19}$$

In Figure3(a) and 3(b) we compare the conventional image transformation method and our method at DCT level. The latter is not only simpler and faster than the former but also has no information loss. Note that the dequantization step is required even for our method in Figure3(b) due to different quantization values for different locations in the DCT block as shown in (1).

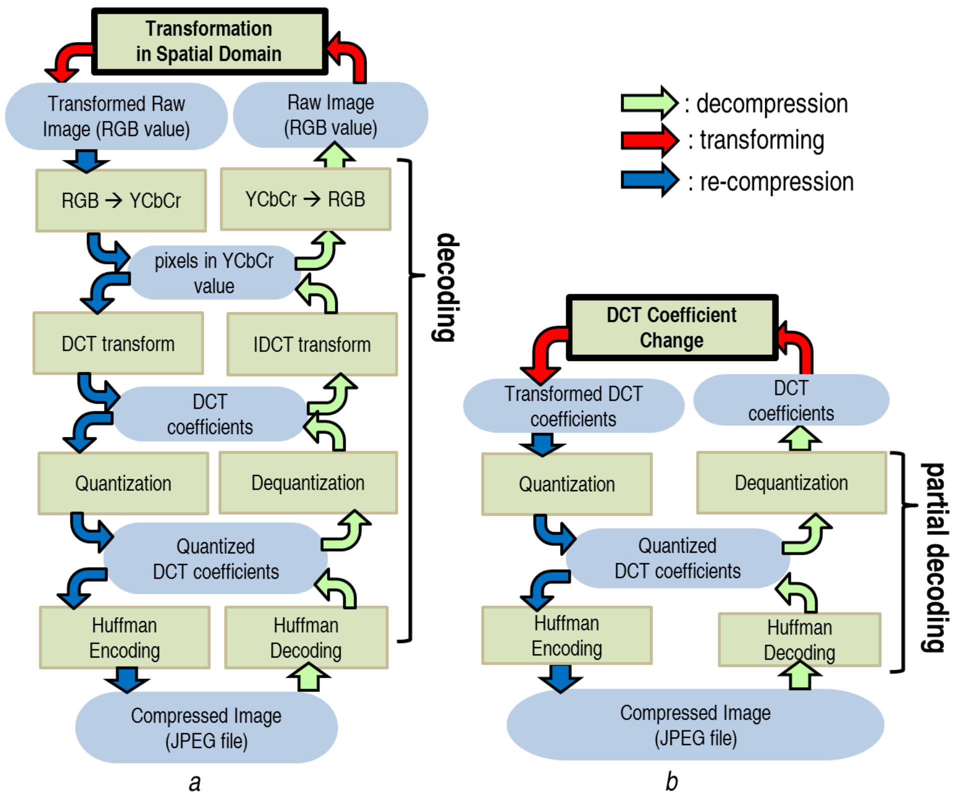

Figure 3. Comparison between Two Intra-Block Transformation Methods: (a) JPEG Image Transformation by Conventional Method, (b) Proposed JPEG Image Transformation

2.2. Whole Image Rotation Algorithm in DCT-Domain

Now we describe how to rotate the whole JPEG image. Figure 4 illustrates our overall approach. It begins with 8x8 blocks from JPEG image, then rotates each block, and relocates the blocks into correct position to form the rotated image.

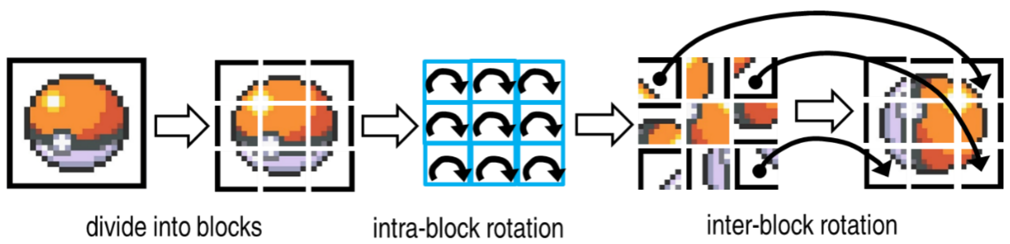

Figure 4. 90° CW Rotation by Intra-Block Rotation and Inter-Block Rotation

Assume that JPEG file consists of NxM DCT blocks, where each block consists of 8x8 pixels and N and M are the number of DCT blocks in the row and column respectively. We decompress JPEG partially to obtain matrices of DCT blocks and change the DCT coefficients for the local intra-block rotation of each DCT block, then we re-arrange the rotated DCT blocks to the new proper locations for whole image inter-block rotation. For example, for the 90° CW rotation of whole image, each of DCT block at the location (i, j) for $0 \le i < N$ and $0 \le j < M$ should be relocated to the (j, N-1-i) location. Figure 5 shows an example with N=M=5 and for 90° CW rotations. It is trivial to extend the inter-block relocation method for 90° CW rotation to other transformations such as 90° CCW rotation, 180° rotation, and horizontal/vertical mirroring.

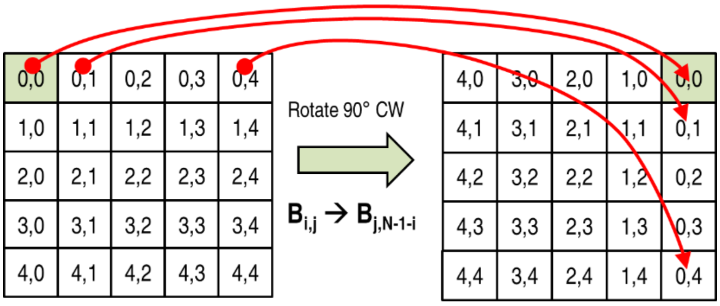

Figure 5. Relocating DCT Blocks for 90CW Inter-Block Rotation

The whole transformation process in pseudo code is shown below. This code describes the transformation for all types of geometric transformations including rotations and mirroring.

Procedure Lossless_Rotate_JPEG

INPUT: JPGfile, trans_type

OUTPUT: JPGtransFile

1. $\{DCT_{i,j} \mid i,j = 0,..,N-1\} \leftarrow$ Decompress_partial(JPGfile)

2.for each $DCT_{i,j}$ loop begin

2.1 Change coefficients of $DCT_{i,j}$ according to(7)~(11) by trans_type

2.2 switch (trans_type) begin

case 90°CW: $DCT_{i,j}$ location (i',j') := (j, N-1-i)

case 90°CCW: $DCT_{i,j}$ location (i',j') := (M-1-j,i)

case 180° : $DCT_{i,j}$ location (i',j') := (M-1-j,N-1-i)

case H-mirroring : $DCT_{i,j}$ location (i',j') := (i,M-1-j)

caseV-mirroring : $DCT_{i,j}$ location (i',j') := (N-i-1, j)

end switch

end for

3. Generate JPGtransFile by encoding with { ($DCT_{i,j}$,i',j')

3. Experimental Results

We implemented the method and conducted experiments using several JPEG images to compare the image quality and relative CPU time required. In the Figure 6 we depict the experimental flow with our proposed method. For any given number of transformations, we compared the quality of image rotated by our proposed method with the rotated original BMP file which has no loss of information at all.

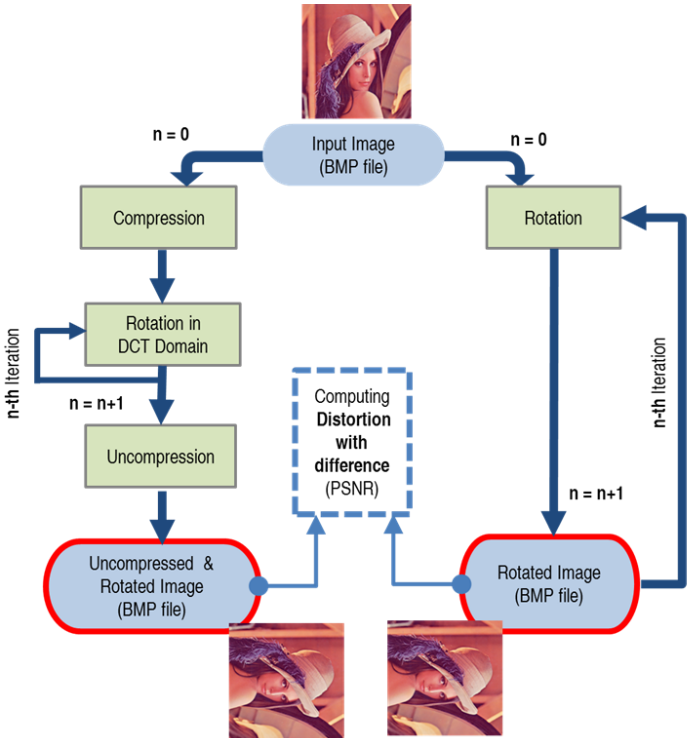

Figure 6. Experimental Procedure to Prove the Quality of Images by Our Rotation Method

We present a part of experimental results in terms of PSNR and SSIM in the Table 1 and Table 2. In Table 1 and Table 2, the '*ST*' means conventional JPEG spatial transformation while '*Ours*' means the proposed transformation. We tested three types of rotations: 90° CW, 90° CCW, and 180° Rotation. In the table sand figures below, the '*Org*' means the image with one-time compressed from the original image bitmap. The experimental data is obtained by means of procedure in Figure 1 for conventional method and Figure6 for our proposed method. Note PSNR of *Ours*in the tables are all constant due to no difference between images with any number of rotations. In Figure 7 and Figure 8 (*Org*)-(*ST*) and (*Org*)-(*Ours*) mean the differences between original image and rotated image generated by *ST* and *Ours*, respectively. Note the (*Org*)-(*Ours*) are black images since there is no differences between them.

Table 1. PSNR(dB) of JPEG Images after Each Number of Rotations

Type	90° CW Rotation				90° CCW Rotation				180° Rotation			
# Rotations	1	4	40	100	1	4	40	100	1	4	40	100
ST	32.7	30.8	18.3	15.3	32.7	30.7	19.0	15.7	32.7	30.9	19.2	15.9
Ours	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7	32.7

Table 2. SSIM of JPEG Images after Each Number of Rotations

Type	90° CW Rotation				90° CCW Rotation				180° Rotation			
# Rotations	1	4	40	100	1	4	40	100	1	4	40	100
ST	0.985	0.980	0.878	0.833	0.985	0.980	0.878	0.830	0.985	0.981	0.896	0.854
Ours	0.985	0.985	0.985	0.985	0.985	0.985	0.985	0.985	0.985	0.985	0.985	0.985

Org | Result by ST | Result by Ours | (Org)-(ST) | (Org)-(Ours)

Figure 7. Lena Image Quality Loss after 40 Rotations by ST and Ours

Org | Result by ST | Result by Ours | (Org)-(ST) | (Org)-(Ours)

Figure 8. Mandrill Image Quality Loss after 40 Rotations by *ST* and Ours

In the Figure 9 we show a graph that illustrates the quality distortions with different number of transformation and different types of transformation. In the graph, R90CW, R90CCW, Rot180, mirrHor, and mirrVer means 90° CW Rotation,90° CW Rotation, 180° Rotation, mirroring horizontal, and mirroring vertical transformation, respectively, by conventional method. 'Ours' in the figure means proposed method for all types of transformations. Our method does not change the quality of JPEG image because there is no information loss with any type of geometric transformation as explained Section 2.

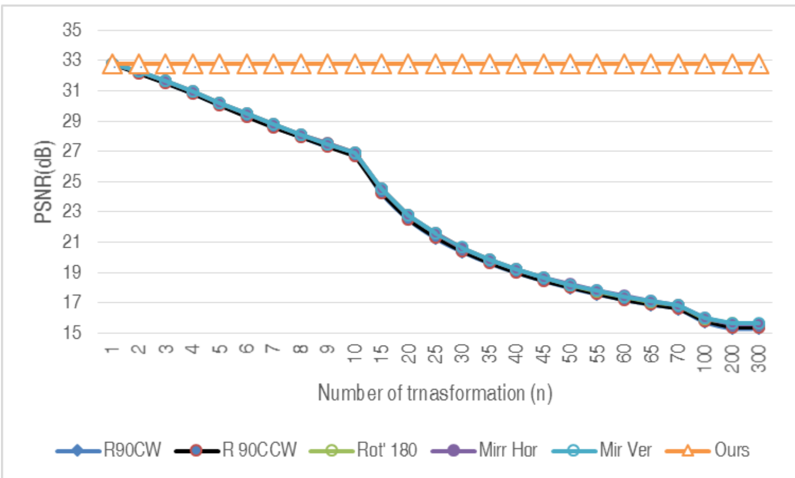

Figure 9. Overall Image Quality Loss by Rotation with Existing Approach with different Types of Geometric Transformation

In addition, based on the experimental results, the computing time of our method is reduced by 43% on average compared to that of conventional method. Finally, we compared the results with 'JPEGRotator' [9]. The quality of images is the same but the computing time is longer than ours by 13.0% on average. Table 3 shows the required computing time of JPEGrotatorand our proposed JPEG rotator.

Table 3. Computing Time Required by each Method for different Transformation (sec)

	JPEGRotator(A)	Ours(B)	(A-B)/A (%)
CW90	49.133	48.067	2.2%
CCW90	52.800	44.067	16.5%
Rot180	54.600	47.333	13.3%
mirr_V	57.400	47.733	16.8%
mirr_H	53.200	44.733	15.9%
Average	53.427	46.387	13.0%

4. Conclusion

In this paper, we proposed a fast and lossless transformation method for compressed images including rotations by a multiple of 90° or horizontal/vertical mirroring. The proposed transformation consists of local rotation with DCT coefficient changes in each DCT block and of whole image rotation with relocation of the changed DCT blocks. This transformation also proved to be faster than conventional method.

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Authors

Kang Yi, received the B.S, M.S. and Ph.D. in computer. Engineering from Seoul National University, Seoul, Korea in 1990, 1992, 1997, respectively. From 1999, he is with school of computer science and electrical engineering of Handong Global University in Pohang, Korea as a faculty member. His current research interest includes image processing for vehicular application, video/image encryption and integrity assurance.

Jeong-Hyun Joo, received the B.S in Computer Engineering and Electrical Engineering from Handong Global University in 2014. He is pursuing MS degree in Computer Engineering in Seoul National University, Korea. His research interests includes algorithm design and analysis and video encryption.

Kyungmi Kim, received the B.S. degree in mathematical education from Korea University, M.S. degree in graduate school of business from Hankuk University of Foreign Studies, and Ph.D. degree in computer engineering from Kyungpook University. She has been a faculty member of Handong Global University in Korea since 1997. Her research interests includes Wireless Sensor Networks, Programming education, and Image processing.