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JPEG COMPRESSION OF MONOCHROME 2D-BARCODE IMAGES USING DCT COEFFICIENT DISTRIBUTIONS

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ABSTRACT

Two dimensional (2D) barcodes are becoming a pervasive interface for mobile devices, such as camera phones. Often, only monochrome 2D-barcodes are used due to their robustness in an uncontrolled operating environment of camera phones. Most camera phones capture and store such 2D-barcode images in the baseline JPEG format. As a lossy compression technique, JPEG does introduce a fair amount of error in the decoding of captured 2D-barcode images. In this paper, we introduce an improved JPEG compression scheme for such barcode images. By altering the JPEG compression parameters based on the DCT coefficient distribution of such barcode images, the improved compression scheme produces JPEG images with higher PSNR value as compared to the baseline implementation. We have also applied our improved scheme to a real 2D-barcode system - the QR Code and analyzed its performance against the baseline JPEG scheme.

Index Terms— Image processing, image restoration, image coding, image analysis, optical image processing

1. INTRODUCTION

Monochrome 2 dimensional (2D) barcodes, such as QR Code [1] and Data Matrix [2] are becoming a pervasive interface for mobile devices, especially for camera phones [3]. Most camera phones store captured barcode images in the baseline JPEG format [4]. This is especially true for mobile devices, where their low-end hardware and software required a low complexity codec. Furthermore, as a lossy compression scheme, JPEG does introduce a fair amount of error in the decoding of captured 2D-barcode images. Fortunately, there is still some control on the parameters of the JPEG algorithm to adapt it for different image types. Compression of images with different contents by varying these parameters has received significant attention in the recent past [5, 6, 7].

The discrete cosine transform (DCT) is at the core of the JPEG compression scheme, together with scalar quantization and entropy coding. It is known that the DCT coefficients for natural images can be modeled with a Laplacian distribution [8]. It is also known that the DCT coefficient for text based images can be modeled with a Gaussian distribution [9]. This knowledge can be employed to improve the compression efficiency of JPEG, by shifting the decoding value from the mid-point of the codeblock to the centroid of the image, thus, giving its minimum mean-square-error [7]. This principle can be applied to other image types, provided we have *a priori* knowledge about the distribution characteristics of the image type.

In this paper, we examine how we can model the DCT coefficients for images of monochrome 2D-barcodes. Similar to [8], we also use a doubly stochastic model, where the distribution of the variance of the 8×8 blocks is key to the analysis. This model is detailed in Section 2. We will then incorporate this knowledge into our design of a decompression scheme for monochrome 2D-barcode images in Section 3, as an improvement over the baseline JPEG decoder. This is achieved by varying the quantization matrix for monochrome 2D-barcode images. We also examine how much improvement in peak signal to noise ratio (PSNR) this method can attain in Section 4. We have also applied our improved scheme to a real monochrome 2D-barcode system - the QR Code. Our experiment and its findings are presented in Sections 5 and 6. Finally, conclusion can be found in Section 7.

2. IMAGE MODEL

Most monochrome 2D-barcodes comprise of squares of monochrome cells. After the process of locating the barcode symbol in an image and pre-processing the barcode symbol for image distortions, often only the data area of the pre-processed barcode symbol is decoded for data retrieval. Thus, without loss of generality, we can assume a randomized monochrome 2D-barcode as depicted in Figure 1, as the basis for our image model.

Fig. 1. A randomized monochrome 2D-barcode.

A doubly stochastic model for the coefficient statistics has been shown to be very effective [8] in modeling DCT distributions of JPEG images. In the 8×8 blocks used for DCT, assuming that the pixels are identically distributed, the DCT coefficient is approximiately Gaussian. Note that we do not need the pixels to be independent. Let I denote the coefficient, and σ^2 denote the variance of the block, then we have [8]

$$P(I|\sigma^2) = \frac{1}{\sqrt{2\pi}\sigma}e^{-\frac{I^2}{2\sigma^2}}. \tag{1}$$

In a doubly stochastic model, the block variance is itself a stochastic quantity. The actual DCT coefficient is given by

$$P(I) = \int_0^\infty P(I|\sigma^2)P(\sigma^2)d(\sigma^2). \qquad (2)$$

From (2), we can see that $P(\sigma^2)$ is a determining factor for the distribution of the DCT coefficients.

For natural images, [8] and other literatures have shown that the distribution of the DCT coefficient is Laplacian. For text documents, [9] has shown that the distribution of the DCT coefficient resembles a Gaussian distribution. Both distributions can be considered special cases of the generalized Gaussian distribution.

Figure 2 shows the distribution of the block variance for the 2D-barcode in Figure 1 mapped against a Gaussian distribution. Figure 3 shows the distribution of the block variance for the 2D-barcode in Figure 1 mapped against a Lapacian distribution. Neither is a good fit.

Unlike text documents or natural images, our model of a randomized monochrome 2D-barcode has equal distribution of monochrome spaces, thus the distribution of its DCT coefficients are equally distributed between two extremes, the central distribution attributed to the white spaces and the constant flat tail distribution attributed to the black spaces. Hence, unlike text documents, it does not have a large concentration of the variance at or near zero, which was attributed to the white background in text documents, and a nearly uniform distribution of the variance otherwise. Unlike natural images, it also does not have different gradients of variance distributed Laplacian-wise from zero, which correspond to the different grayscale values.
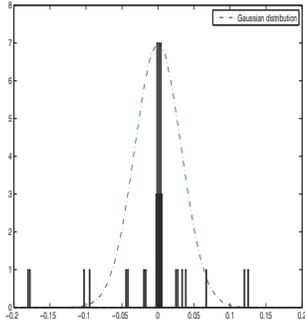
Fig. 2. Gaussian fit to DCT distribution of block variance for the monochrome 2D-barcode.

In fact, the DCT coefficient distribution of our randomized monochrome 2D-barcode has a 'single-pulse' like concentration of variance at or near zero and a flat tail of one otherwise. To best model such a distribution, we have modified the Laplacian distribution [8] as

$$P(I) = \frac{1}{2\beta}e^{-\frac{|I|}{\beta}} + \alpha, \qquad (3)$$

where $0.0011 < \beta < 0$ and $\alpha = 1$, so that our modified distribution has a 'single-pulse' like concentration of variance at or near zero and a flat tail of one otherwise. This is achieved by reducing the β value to nearly 0 and setting the α value to 1.

Equation (3) is fitted to the DCT coefficient distribution of our randomized monochrome 2D-barcode model in Figure 4.

Although not a perfect fit, our modified Laplacian does present a better fit to the DCT coefficient distribution of the randomized
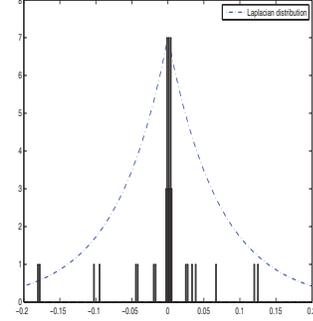
Fig. 3. Laplacian fit to DCT distribution of block variance for the monochrome 2D-barcode.
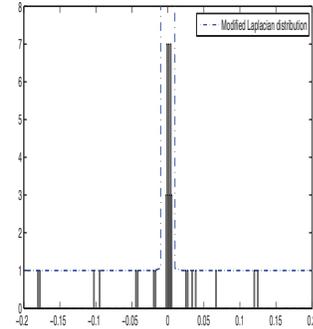
Fig. 4. Modified Laplacian fit to DCT distribution of block variance for the monochrome 2D-barcode.

monochrome 2D-barcode image, than the Gaussian distribution or the unmodified Laplacian distribution.

3. IMPROVED DECOMPRESSION SCHEME

To improve the decompression of monochrome 2D-barcode images, we have used the modified Laplacian distribution in (3) to model the AC coefficients in the JPEG decoder. Assuming the codeblock ranges from a to b. In JPEG, when the quantization table at that frequency is Q_j the code value for that block is k, (without loss of generality, assuming $k > 0$ for the calculation below), then $a = (k - 0.5)Q_j$ and $b = (k + 0.5)Q_j$. The centroid of this range is

$$
\begin{aligned}
\hat{x} &= \frac{\int_a^b (x\frac{\lambda}{2}e^{-\lambda x} + \alpha)dx}{\int_a^b (\frac{\lambda}{2}e^{-\lambda x} + \alpha)dx} \\
&= \frac{\frac{1}{2}[-xe^{-\lambda x} - \frac{1}{\lambda}e^{-\lambda x}]_a^b + \alpha(b-a)}{\frac{1}{2}(e^{-\lambda a} - e^{-\lambda b}) + \alpha(b-a)} \\
&= \frac{\frac{1}{2}(ae^{-\lambda a} + \frac{1}{\lambda}e^{-\lambda a} - be^{-\lambda b} - \frac{1}{\lambda}e^{-\lambda b}) + \alpha(b-a)}{\frac{1}{2}(e^{-\lambda a} - e^{-\lambda b}) + \alpha(b-a)},
\end{aligned}
$$
$$(4)$$

where $\lambda = \frac{1}{2\beta^2}$.

Hence, in our improved decompression scheme, we shift the decoding value according to (4) with our modified values for α and β. Accordingly, this will give our improved scheme the minimum mean-square error [7].

4. SIMULATION

To test our improved scheme, we evaluated the performance of the algorithm on 425 randomly generated monochrome 2D-barcode images similar to that of Figure 1. Each image is of size 256×256 pixels.

Our evaluation is performed comparing our improved decompression scheme against the baseline JPEG, which does not assume any distribution in the coefficients. We record the average PSNR of the resultant images as compared to their respective original under each scheme.

The average PSNR results from simulation of the two approaches are summarized in Table 1.

Table 1. Average PSNR results from simulation.

JPEG scheme	Average PSNR
Baseline scheme	30.785 dB
Improved scheme	31.415 dB

These results indicate that for monochrome 2D-barcode images, our improved decompression scheme, using a biased reconstruction based on the modified Laplacian distribution, produces an image with better quality. Thus, our scheme can lead to a reduction of lossy compression error introduced by the baseline JPEG scheme in the decoding of monochrome 2D-barcode. Nonetheless, how such an improved scheme would perform for real monochrome 2D-barcode images? To find out, we have conducted experiment using a typical monochrome 2D-barcode - the QR Code.

5. TESTING OUR FINDINGS WITH REAL BARCODE IMAGES

To further test our improved scheme, we have evaluated the performance of the algorithm on a set of real monochrome barcode images, namely the monochrome QR Code. This 2D-barcode was choosen because:

- The source code to its software encoder and decoder is available on the personal computer (PC) platform, thus, we can modify the software to encode and decode 2D-barcodes using our improved JPEG scheme. The source code of QR Code encoder and decoder is available from the Open Source QR Code Library at http://qrcode.sourceforge.jp/.

We have tested our improved scheme by encoding 100 samples of the QR Code using random samplings of text from our book on 2D-barcodes for mobile devices [10]. The 2D-barcode images from the encoder are further saved as compressed JPEG images using both our improved and the baseline JPEG scheme. Thus, for this experiment, we have 200 JPEG images of the QR Code, where 100 is compressed using the baseline JPEG scheme and the remainder is compressed using our improved JPEG scheme.

To evaluate the performance of our improved scheme for the mobile camera phone platform, we have further processed these 2D-barcode JPEG images by adding channel noise according to those experienced by barcodes images captured using a camera phone [11].

We then decompress the JPEG barcode images using their corresponding JPEG scheme and decode the relevant barcode using their respective software decoder.

For this experiment, we have recorded the results of the average PSNR value of the images compressed using each JPEG scheme, their decoding success rates and presented discussion on their possible cause for errors. These findings are presented in the following section.

6. RESULTS FROM EXPERIMENT WITH REAL BARCODE IMAGES

For this experiment, we have tested our improved JPEG scheme using a monochrome QR Code, as illustrated in Figure 5.

Fig. 5. An example of the monochrome QR Code used in our experiment.

The monochrome QR Code 2D-barcode image in Figure 5 is comprising of 315×315 pixels.

6.1. Monochrome QR Code

For the QR Code 2D-barcodes, we have observed that the monochrome nature of the barcode allows it to have a robust error tolerance even under channel noise and JPEG quantization errors. Table 2 presents a comparison of the monochrome QR Code 2D-barcode average PSNR value and decoding success rate for the baseline JPEG scheme versus our improved JPEG scheme.

Table 2. Comparison of average PSNR values (in dB) and barcode decoding success rate (in %) from the QR Code experiment.

	Baseline JPEG scheme	Improved scheme, $\beta = \frac{1}{900}$
Average PSNR value (in dB)	27.164	27.371
Barcode decoding success rate (in %)	100	100

Visually, examples of the QR Code images with channel noise and JPEG quantization errors are presented in Figures 6 and 7.

The above finding is obvious when we analyze the movement of the monochrome colors when the QR Code 2D-barcode image is subjected to channel noise and JPEG quantization errors. [1] These color movements is illustrated in Figure 8.

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[1]A color movement is the vector difference in RGB color co-ordinate space of a given color from it original state to its JPEG quantized with channel noise state.

Fig. 6. An example of the monochrome QR Code compressed using the baseline JPEG scheme in our experiment.

Fig. 7. An example of the monochrome QR Code compressed using our improved JPEG scheme in our experiment.
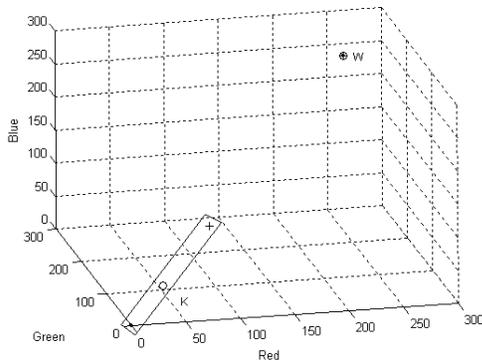
Fig. 8. monochrome colors movements of the QR Code images used in our experiment.

In Figure 8, the two colors are black (K) and white (W), which is represented in their Red, Green, Blue (RGB) values of (0,0,0) and (255,255,255), respectively. In Figure 8, the symbol ($\bullet$) represents the original average RGB values for the two monochrome colors; the symbol ($+$) represents the average RGB values for the two monochrome colors with channel noise and baseline JPEG quantization errors, and the symbol ($\bigcirc$) represents the average RGB values for the two monochrome colors with the same channel noise and our improved JPEG quantization errors. Note that in Figure 8, while the color white (W) RGB values never moved irrespective of the channel noise level and JPEG quantization errors, the color black (K) RGB values shifted closer towards the color white (W) as the sum of channel noise plus JPEG quantization errors increases, and the average image PSNR decreases. From Figure 8, we noted that even under the regular channel noise pertinent to the mobile phone camera capture channel and errors due to different JPEG quantizations, the average RGB values for the color black (K) (the values bounded by the rectangle box) is still at a significant distance apart from the average RGB value of the color white (W). Hence, the monochrome nature of the colors for the QR Code made it robust against errors, such that the utility of improvement in JPEG compression for such monochrome 2D-barcode images is superfluous. Thus, the improvement in JPEG dequantization errors from our proposed scheme does not affect the successful decoding rate for monochrome 2D-barcodes such as the QR Code.

7. CONCLUSION

In this paper, we have extended the analysis of DCT distribution modelling to images of randomized and real monochrome 2D-barcode images. Our modified Laplacian distribution model is a better fit to the analyzed DCT distributions when compared to either the Gaussian distribution or the unmodified Laplacian distribution models. Using this model, we have proposed an improved decompression scheme, which produces better image quality for JPEG compression of monochrome 2D-barcodes. We have also tested our improved scheme and compared it performance to the baseline JPEG schemes for compressing monochrome QR Code 2D-barcode images in the mobile phone camera capture channel environment. Due to the robustness of the monochrome colors used in such 2D-barcodes against introduced channel noise and JPEG quantization errors, we have found that the utility of improvement in JPEG compression for such monochrome 2D-barcode images is superfluous. Hence, it can be concluded that the improvement in JPEG dequantization errors from our improved scheme does not affect the successful decoding rate for monochrome 2D-barcodes such as the QR Code. The next step will be for us to extend this work to color 2D-barcode images, especially those used for pervasive computing with camera mobile phones.

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