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Improving mobile color 2D-barcode JPEG image readability using DCT coefficient distributions

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IMPROVING MOBILE COLOR 2D-BARCODE JPEG IMAGE READABILITY USING DCT COEFFICIENT DISTRIBUTIONS

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ABSTRACT

Two dimensional (2D) barcodes are becoming a pervasive interface for mobile devices, such as camera smartphones. Often, only monochrome 2D-barcodes are used due to their robustness in an uncontrolled operating environment of smartphones. Nonetheless, we are seeing an emerging use of color 2D-barcodes for camera smartphones. Most smartphones 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 captured 2D-barcode images. In this paper, we analyzed the Discrete Cosine Transform (DCT) coefficient distributions of generalized 2D-barcodes using colored data cells, each comprising of 4, 8 and 10 colors. Using these DCT distributions, we improved the JPEG compression of such mobile barcode images. By altering the JPEG compression parameters based on the DCT coefficient distribution of the barcode images, our 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 10 colors 2D-barcode system; and analyzed its performance in comparison to the default and alternative JPEG schemes. We have found that our improved scheme does provide a marked improvement for the successful decoding of the 10 colors 2D-barcode system.

***Index Terms*—** JPEG image readability, color mobile barcode, mobile computing, pervasive computing

1. INTRODUCTION

We note that most color mobile 2D-barcodes use only 4 or 8 colors for camera smartphones and the novel MMCC^{TM}2D-barcode uses at least 10 colors. Thus, in this paper, we will analyze the generalized models for 4, 8 and 10 colors 2D-barcodes.

Many 2D-barcodes decoding softwares on camera smartphones take the approach of capture and store the 2D-barcode images first before decoding [1]. Many camera smartphones store the captured barcode images in the baseline Joint Photographic Experts Group (JPEG) format [2]. As a lossy compression scheme, JPEG does introduce a fair amount of error in the 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 [3, 4, 5].

1.1. Approaches to improve JPEG image quality

It is well known that setting the quantization and dequantization matrices to be the same for all types of applications does not give the best image quality, when we have information about the statistics of the transform coefficients [6]. It is also known that the DCT coefficients for natural images can be modeled with a Laplacian distribution [7]. Furthermore, it is known that the DCT coefficient for text based images can be modeled with a Gaussian distribution [8]. 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 (MSE) [5]. Different approaches have been proposed to achieve this.

In this paper, we analyzed the distributions of the DCT coefficients for images of color mobile 2D-barcodes. Similar to [7], we also use a doubly stochastic model, where the distribution of the variance of the 8×8 blocks is key to the analysis. Then using these distributions of the DCT coefficients for images of color mobile 2D-barcodes, we improved the decompression of such images, thus, producing JPEG images with higher PSNR values as compared to the baseline JPEG implementation. We also compared our approach to those presented in [6] and [9].

2. COLOR 2D-BARCODES MODELS AND BIASED RECONSTRUCTION

Using the same approach as for monochrome 2D-barcodes in our previous work [10], we assume randomized color 2D-barcodes as depicted in Figures 1, 2 and 3, as the basis for our image model for color mobile 2D-barcodes using 4, 8 and 10 colors.

For the 4 colors model, we have selected the color set of Black $(1, 1, 1)$, Red $(1, 0, 0)$, Green $(0, 1, 0)$ and Blue $(0, 0, 1)$ from the RGB color space because these color are furthest apart and thus is often used as the 4 colors of choice. The color White $(0, 0, 0)$ is omitted because this is often used as the "separator" color or "quiet zone" color for mobile 2D-barcodes [11]. For the 8 colors model, we have selected the color set of Black $(1, 1, 1)$, White $(0, 0, 0)$, Red $(1, 0, 0)$, Green $(0, 1, 0)$, Blue $(0, 0, 1)$, Magenta $(1, 0, 1)$, Cyan $(0, 1, 1)$ and Yellow $(1, 1, 0)$ from the RGB model because these are furthest apart 8 colors in that color space. As for the 10 colors model, we have adopted the 10 colors of choice provided by the MMCC™2D-barcode paper [12]. This is because the MMCC™has a novel color selection scheme which allowed it to use more colors than any other mobile 2D-barcodes.

Fitting equation (3) from [10] to the DCT coefficient distribution of our randomized color 2D-barcode models, we observed the following plots as depicted in Figures 4, 5 and 6.

It is interesting to observe that as we increase the 2D-barcode colors from 4 to 8, there is a 'thickening' in the concentration of variance distribution of DCT coefficients at or near zero. This observation can be explained by the fact that for color images, the JPEG compression algorithm processes each R, G and B layer separately as grayscale images. Thus, with the increase of colors from 4 to 8, the number of grayscale pixels in each of the R, G and B layer will also increase. Nonetheless, as these pixels are dominantly comprising of $\{0, 1\}$ values, thus, their variance, similar to monochrome pixels, are concentrated at or near zero.

Most interesting is the observation of the distribution of DCT coefficients for our 10 colors model. It seems that instead of further spreading the concentration of the DCT coefficient variance at or near zero, our choice of the MMCC™10 colors actually further focuses the variance distribution of the DCT coefficients closer around the zero value. This may be due to the unique color selection scheme of the MMCC™2D-barcode.

From plots in Figures 4, 5 and 6, it seems that equation (3) from [10] only fits well to our 10 color model. Thus, for our 4 and 8 colors model we further manipulated the β values, such that for the 4 colors model, $\beta = \frac{1}{350}$ and for the 8 colors model, $\beta = \frac{1}{200}$. These modified Laplacian distributions are plotted against the DCT coefficients distributions of our 4 and 8 colors model in Figures 7 and 8.

Just as in [5], we can conclude that if $I(x, y)$ is not uniformly distributed, $I_{qe}(x, y)$ would also be non-uniform with the quantization scheme. Thus, a biased reconstruction from the mid-point to the centroid of each code block will therefore enhance the image decompression, which is the approach we have adopted for our color 2D-barcode models, in the similiar way as our approach in [10].

3. SIMULATION RESULTS

To test our improved scheme, we evaluated the performance of the algorithm on 425 samples of each randomly generated color 2D-barcode images similar to that of Figures 1, 2 and 3. 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, and the approaches proposed in [6] and [9]. For [9], we only simulated for the proposal based on equations (5) to (9) in that work. This is because only the λ^q_{ML} of equation (5) therein is computed from the quantized coefficients available at the decoder, hence, only this approach is applicable at mobile decoders such as camera smartphones. 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 four approaches are summarized in Table 1. It is evident that our scheme can lead to a reduction of lossy compression error introduced by the baseline JPEG scheme and biased scheme based on general Laplacian distributions in the decoding of such 2D-barcode images. Nonetheless, how does our improved JPEG scheme perform for decoding real 2D-barcodes, especially for mobile environment?

4. TESTING OUR FINDINGS WITH REAL BARCODE IMAGES

To further test our improved scheme, we have evaluated the performance of our algorithm on real barcode images, namely the 10 colors MMCC™2D-barcodes. These color 2D-barcodes were choosen because the source code of the MMCC™encoder and decoder is available to us as we are the inventors of this 10 colors 2D-barcode [12].

We have tested our improved scheme by encoding 100 samples of the MMCC™using random samplings of text from our book on 2D-barcodes for mobile devices [12]. The 2D-barcode images from these encoders are further saved as compressed JPEG images using both our improved and the default JPEG scheme. For the 10 colors MMCC™2D-barcode samples, we also compressed the barcodes using the biased JPEG schemes of [6] and [9]. Thus, for this experiment, we have experimented with 400 JPEG images of the MMCC™, where each set of 100 2D-barcode images is compressed using the default JPEG scheme, our improved JPEG scheme, the biased JPEG scheme of [6] and the biased JPEG scheme of [9], respectively.

To evaluate the performance of our improved scheme for the mobile camera smartphone 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 [13].

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.

5. RESULTS FROM EXPERIMENT WITH REAL BARCODE IMAGES

For this experiment, we have tested our improved JPEG scheme using a MMCC^{TM}2D-barcode.

The MMCC^{TM}2D-barcode image used is comprising of 1366×1348 pixels and is not square-shaped due to the fact that the MMCC^{TM}2D-barcode's finder pattern resides outside of its data area, thus, while its data area is square in shape, its total barcode area is not [12].

5.1. 10 colors MMCC^{TM}

For the MMCC^{TM}2D-barcodes, we have found that the use of our improved JPEG scheme makes a notable difference in the decoding success rate of the 2D-barcode images under channel noise conditions that is comparable to the mobile phone camera capture channel [13]. Thus, for this 10 colors 2D-barcode, we have experimented with all four JPEG schemes presented in Table 1.

Table 2 presents a comparison of the 10 colors MMCC^{TM}2D-barcode average PSNR value and decoding success rate, respectively for each of the four JPEG schemes presented in Table 1.

A sample of the MMCC^{TM}2D-barcode used in our experiment is illustrated in Figure 9.

The findings of Table 2 can be interpreted as, when subjected to the channel noise of our experiment, the baseline JPEG compression scheme produced 10% of MMCC^{TM}2D-barcode images that resulted in decoding errors. These errors are resulted when even the 22% forward error correction coding provided by the Reed-solomon coding cannot correctly recover the data in error. On the otherhand, all three improved JPEG compression schemes produced MMCC^{TM}2D-barcode images that resulted in 100% decoding success. To find an explanation for this finding we have analyzed the image quality of these improved JPEG schemes from two prespectives, namely visually and qualitatively.

For our analysis, we have focused in particular at 3 colors out of the 10 used in the MMCC^{TM}, namely the color Sky Blue (S), the color Cyan (C) and the color White (W). The respective RGB values of these 3 colors are S= $(128, 255, 255)$, C= $(0, 255, 255, 255)$ and W= $(255, 255, 255)$ and these colors are marked according to their S, C and W alphabet symbols in the reference color area of the MMCC^{TM}2D-barcode in Figure 9.

To analyze the visual quality of the images produced by our four JPEG schemes, we have focused our attention to a small rectangle area of data cells, near the top left corner of the MMCC^{TM}2D-barcode. An example of this focus area is also illustrated in the MMCC^{TM}2D-barcode in Figure 9.

Figure 10 presents the visual differences comparing between the original image to the image quality from the default baseline JPEG scheme (marked as 'DEFAULT'), and the image quality from the improved JPEG schemes. (Note: As all three improved JPEG schemes produced images with visually similar qualities, only one sample is used in this Figure to represent all three schemes; and this sample is marked aptly as 'IMPROVED'.) From this visual inspection, we noted that for the DEFAULT image, the color Sky Blue (S) is getting harder to differentiate visually from the color White (W), while the color Cyan (C) is visually looking more like Sky Blue (S) in the same image. As for the IMPROVED image, these colors are visually more representative of their original hues as in the ORIGINAL image.

To further analyze these observations, we analyzed the movement of the 3 colors when the MMCC^{TM}2D-barcode image is subjected to channel noise and JPEG quantization errors. These color movements is illustrated in Figure 11.

In Figure 11, the symbol ($\bullet$) represents the original average RGB values for the 3 colors S, C and W; the symbol $(+)$ represents the average RGB values for the same 3 colors with channel noise and baseline JPEG quantization errors, the symbol ($\square$) represents the average RGB values for the 3 colors with channel noise and the biased JPEG [6] quantization errors, the symbol ($\diamond$) represents the average RGB values for the 3 colors with channel noise and the biased JPEG [9] quantization errors, and the symbol ($\bigcirc$) represents the average RGB values for the 3 colors with the same channel noise and our improved JPEG quantization errors. Note that in Figure 11, while the color white (W) RGB values never moved irrespective of the channel noise level and JPEG quantization errors, the color Sky Blue (S) and the color Cyan (C) 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 11, we noted that under the regular channel noise pertinent to the mobile phone camera capture channel and errors due to the baseline JPEG quantization, the average RGB values for the color Sky Blue (S) and the color Cyan (C) (the symbols $(+)$ within the rectangle boxes) are very close to the average RGB value of the color white (W) and the original color Sky Blue (S), respectively. In the same Figure, we noted that for the three improved JPEG schemes, the average RGB values for the color Sky Blue (S) and the color Cyan (C) are at more distinguishable distances from the average RGB value of the color white (W) and the original color Sky Blue (S), respectively. In fact, in our experiment, our proposed scheme produced the average RGB values for the color Sky Blue (S) and the color Cyan (C) that are furthest away from the average

RGB value of the color white (W) and the original color Sky Blue (S), respectively.

Thus, we can conclude from our experiment that under the normal channel noise pertinent to the mobile camera smartphone capture channel and the baseline JPEG quantization errors, about 10% of the MMCC^{TM}2D-barcode images produced in our random samples have too much errors to be successfully decoded by the software decoder of the MMCC^{TM}, even when a 22% Reed-Solomon error correction [12] is employed. Such errors are likely to be caused by the movement of the reproduced colors away from their original color values and moving towards the values of other colors used in the 10 colors 2D-barcode. We have found that by employing improved JPEG compression schemes, we can reduce the occurances of such colors reproduction errors, thus, improving the success rate of decoding our samples of 10 colors MMCC^{TM}2D-barcode for the mobile phone camera capture channel. Among the three schemes we have investigated, we have found our proposed improved JPEG scheme to give the best performance in terms of having the least colors values movement and resulting in images with the highest PSNR values over all.

6. CONCLUSION

In this paper, we have extended the analysis of DCT distribution modeling [10] to images of randomized color 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 improved the decompression scheme of such images, which produced better image PSNR quality for JPEG compression of color 2D-barcodes images. Our improved JPEG scheme does produce better success rate in decoding of the 10 colors MMCC^{TM}2D-barcode samples in our experiment.

7. REFERENCES

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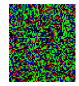

Fig. 1. A randomized 4 colors 2D-barcode.

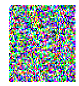

Fig. 2. A randomized 8 colors 2D-barcode.

Fig. 3. A randomized 10 colors 2D-barcode.

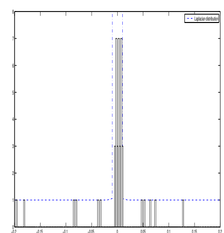

Fig. 4. Modified Laplacian fit to DCT distribution of block variance for the 4 colors 2D-barcode.

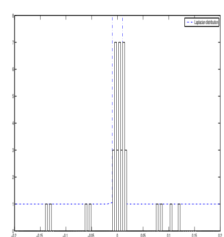

Fig. 5. Modified Laplacian fit to DCT distribution of block variance for the 8 colors 2D-barcode.

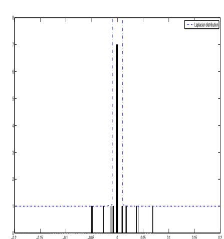

Fig. 6. Modified Laplacian fit to DCT distribution of block variance for the 10 colors 2D-barcode.

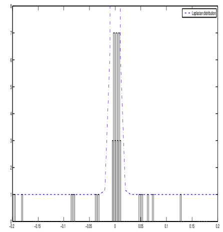

Fig. 7. Modified Laplacian better fitting to DCT distribution of block variance for the 4 colors 2D-barcode.

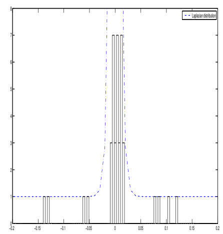

Fig. 8. Modified Laplacian better fitting to DCT distribution of block variance for the 8 colors 2D-barcode.

Table 1. Average PSNR results (in dB) from simulation. (Note: (*): $\beta = \frac{1}{350}$; (**): $\beta = \frac{1}{200}$)

	Baseline JPEG scheme	Biased scheme [6], $\lambda = \frac{\sqrt{2}}{\sigma}\lambda_{ML}^{q}$	Biased scheme [9],	Improved scheme, $\beta = \frac{1}{900}$
4 colors 2D-barcode	30.001	30.115	30.116	30.538 30.657*
8 colors 2D-barcode	28.824	28.853	28.858	29.231 29.558**
10 colors 2D-barcode	29.046	29.136	29.139	29.948

Table 2. Comparison of average PSNR values (in dB) and barcode decoding success rate (in %) from the MMCC^{TM}experiment.

	Baseline JPEG scheme	Biased scheme [6], $\lambda = \frac{\sqrt{2}}{\sigma}\lambda_{ML}^{q}$	Biased scheme [9],	Improved scheme, $\beta = \frac{1}{900}$
Average PSNR value (in dB)	28.633	28.728	28.735	28.837
Barcode decoding success rate (in %)	90	100	100	100

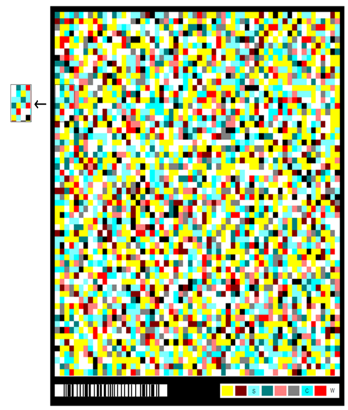

Fig. 9. An example of the MMCC^{TM}2D-barcode image used in our experiment.

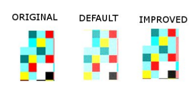

Fig. 10. A visual quality comparison of data cells from a MMCC^{TM}2D-barcode image used in our experiment.

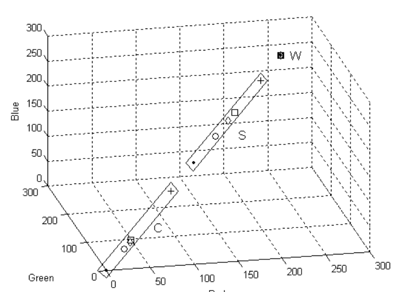

Fig. 11. Three colors movements of the MMCC^{TM}2D-barcode images used in our experiment.