# JPEG color barcode images analysis: A camera phone capture channel model with auto-focus

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### *Abstract*

*As camera phones have permeated into our everyday lives, two dimensional (2D) barcode has attracted researchers and developers as a cost-effective ubiquitous computing tool. A variety of 2D barcodes and their applications have been developed. Often, only monochrome 2D barcodes are used due to their robustness in an uncontrolled operating environment of camera phones. However, we are seeing an emerging use of color 2D barcodes for camera phones. Nonetheless, using a greater multitude of colors introduces errors that can negatively affect the robustness of barcode reading. This is especially true when developing a 2D barcode for camera phones which capture and store these barcode images in the baseline JPEG format. This paper presents one aspect of the errors introduced by such camera phones by modeling the camera phone capture channel for JPEG color barcode images wherein there is camera auto-focus.*

***Keywords:*** *Image-based modeling, Image processing & understanding*

## 1. Introduction

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. Recently we are seeing an emerging use of color 2D barcodes for camera phones. Nonetheless, using a greater multitude of colors introduces errors that can negatively affect the robustness of barcode reading. Furthermore, most camera phones capture and store such color 2D barcode images in the Joint Photographic Experts Group (JPEG) format [1]. As a lossy compression technique, JPEG also introduces a fair amount of error in the decoding of captured 2D barcode images. This JPEG quantization error is further compounded by the error introduced by the camera phone capture channel. Thus, robust decoding of color 2D barcode JPEG images is a very challenging task. When possible, 2D barcode developers would rather not work with such lossy JPEG images [2]. Unfortunately, the most often image format supported on camera phones is the baseline JPEG format. Moreover, there is an increasing use of color 2D barcodes for camera phones. Examples of these color 2D barcodes are the colored ColorCode [3], High Capacity Colour Barcode (HCCBTM) [4] and the Mobile Multi-Colour Composite (MMCCTM) [5] 2D barcode. Figures 1 and 2 presents examples of such color 2D barcodes for camera phones.

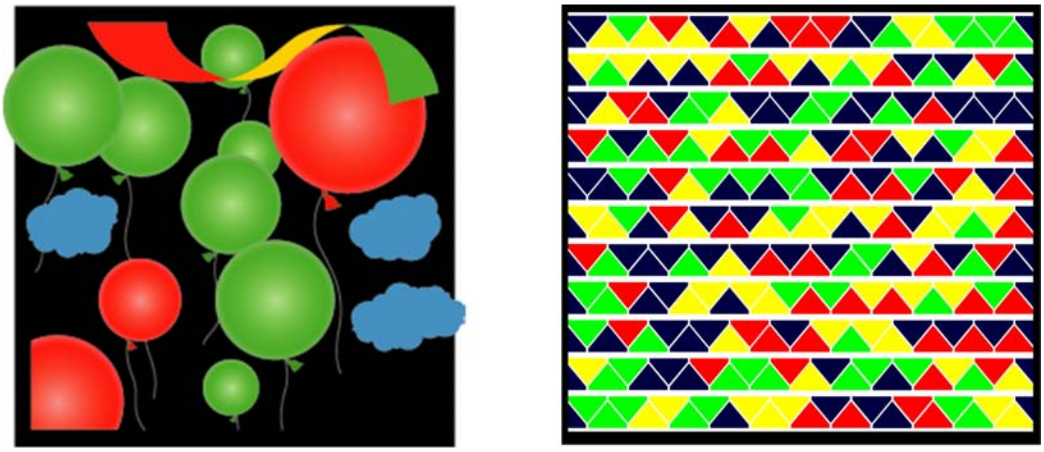

Figure 1. Examples of ColorCode™ (left) and HCCB™(right).

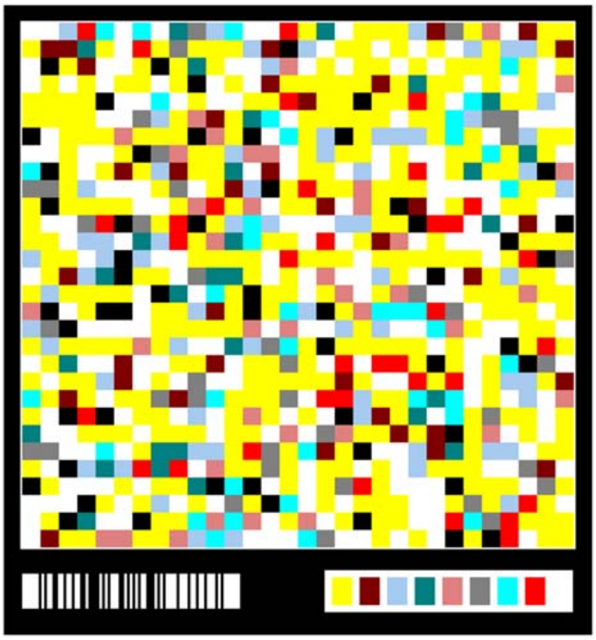

Figure 2. An example of MMCC™

## 1.1 Errors pertinent to JPEG images captured on camera phones

When a 2D color barcode image is captured by a camera phone and stored in JPEG format, there are essentially two major components of introduced errors, other than errors due to corruption of the 2D barcode symbol itself, such as smudges, tear and wear, or errors due to bad illumination of the barcode symbol being captured. These two major components of introduced errors are:

1. Errors due to the JPEG compression technique;
2. Errors due to the camera phone capture channel.

For errors introduced by the JPEG compression, there are essentially two major elements that introduced these errors, namely, the errors due to the quantization process in the JPEG compression, and the errors due to the use of suboptimal de-quantization matrix at the JPEG decoder. There is nothing much that can be done about the former but with the latter, we have found that a JPEG decoder based on optimized Discrete Cosine Transform (DCT) co-efficient distribution can result in higher quality decompressed images [6].

In this paper, we analyzed the other major component of introduced error, the errors due to the camera capture channel. From our research [5] on the MMC™, we have observed that even under controlled laboratory conditions (i.e. perfect 2D barcode symbol and good barcode symbol illumination) there are still signification errors in the captured image such that the colors in the captured image shift significantly from their respective reference color. An example of this observation is presented in Figure 3, where the color of the data symbol, Symbol 7, has shifted from its origin at *RGB* = (0, 255, 255) to a cluster of color co-ordinates within the *RGB* color space.

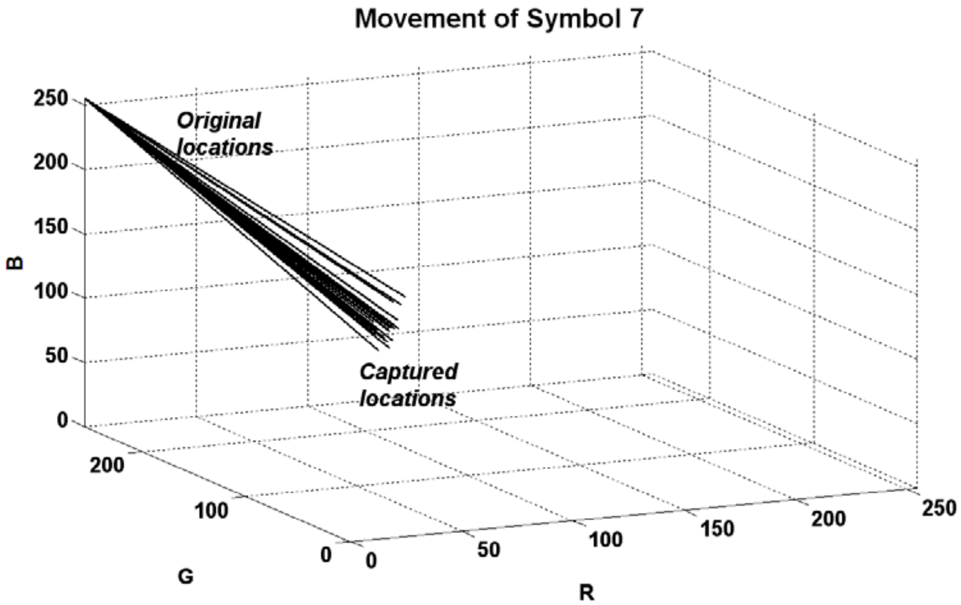


Figure 3. An example of color movement in RGB color space for a capture JPEG color barcode image

Section 2 presents our modeling of one camera phone capture channel wherein the target image is in good focus. Section 3 presents the results of our simulations. Section 4 presents our conclusion.

## 2. Camera phone capture channel modeling

To model our color 2D barcode, we have used the color scheme from our previous work [5] and constructed a data cells only color 2D barcode. Such a data cells only model is valid because in the decoding process for 2D barcodes, the data cells area of the barcode symbol is usually segmented from the located barcode image prior to the color decoding process [5]. An example of our color 2D barcode is depicted in Figure 4.

Figure 4. An example of our color 2D barcode model

For modeling the camera phone capture channel, we have used a Palm Treo 750 smart camera phone. This is a camera phone equipped with a 1.3 megapixel Charged Couple Devices (CCD) camera, with auto-focus on a Windows Mobile Ver.6 operating system. To model the camera capture channel for this camera phone, we have generated 20 random samples of the color barcode model depicted in Figure 4, where for each sample; we have captured 20 JPEG images of the color 2D barcode under controlled laboratory conditions. Figure 5 illustrates a similar setting used in our experiment to model the camera phone capture channel.

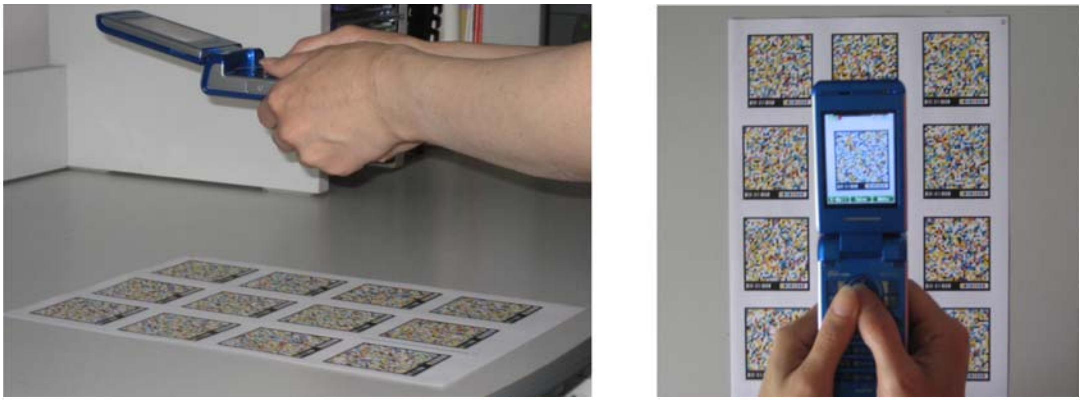

Figure 5. An experiment setting similar to that used in our modeling

From the experiment, after capturing the JPEG images of the color 2D barcode model with our camera phone, we have found that the average observed mean values for the

*Cb* and *Cr* color components of the barcode images do not change but its *Y* luminance component is, on the average, reduced by about 40%. We have analyzed the captured JPEG images in the *YCbCr* domain because the JPEG compression manipulates color images in this domain [1]. While this observation can be attributed to the camera phone capture channel error, it can also be caused by quantization errors in the JPEG compression process of the captured images. Hence, we further compared this observation with JPEG compressed images of the same 2D barcodes samples under ideal conditions (i.e. directly compressing the original barcode images). What we have found is that there is definitely another error component contributing to the changes in the *YCbCr* components of our sample 2D barcode images. Figure 6 presents an example of such an observation.

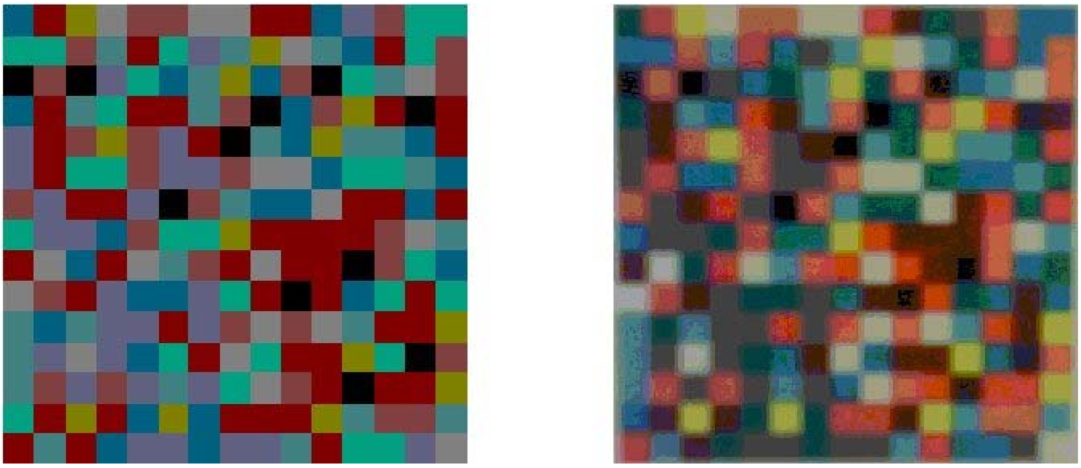

Figure 6. Comparing between a JPEG compressed 2D barcode sample image (left) and its camera phone captured equivalent (right).

To further model for this error component, we have taken steps to reproduce the same color movements using image pre-processing techniques to model the noise in the color 2D barcode sample images prior to the JPEG compression under ideal conditions. Figure 7 illustrates the steps we have taken in this comparative study.

From our study, we have found that we can reproduce, within limits, the error introduced by this auto-focus camera capture channel. These results are presented in the next Section.

## 3. Simulation Results

From our simulations, we have observed that the camera capture channel produces 'darker' images of our sample color 2D barcodes. This is consistent across all our randomized model samples. To reproduce such effects, we have experimented with various image processing algorithms, such as image blurring; image softening, manipulating the image contrast and adding noise to the image. We have also experimented with noise with different distributions, such as Gaussian, Laplacian and Poisson distributed noises.

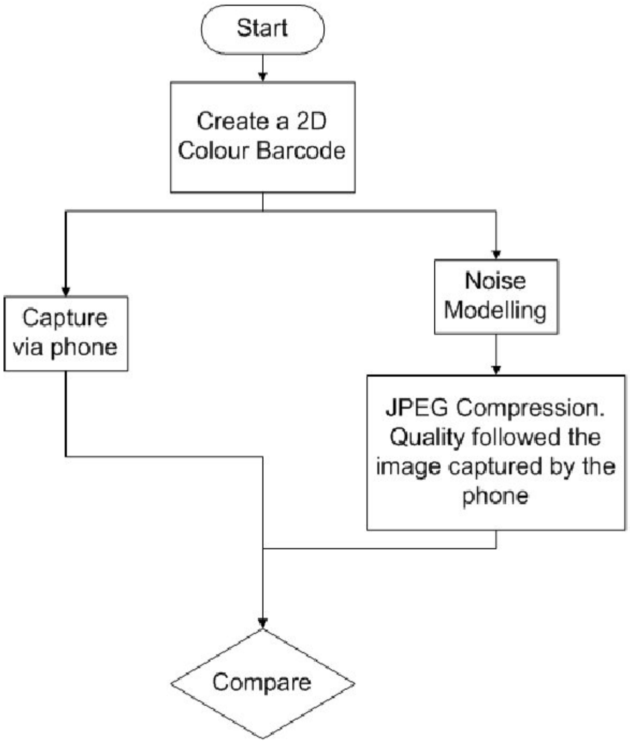


Figure 7. A comparative study between the captured and the pre-processed color 2D barcode images.

From our experiments, we have found that adding Gaussian distributed noise gives us the closest effect to the color movements observed in our camera channel modeling experiment. For Additive White Gaussian Noise (AWGN), we have experimented by adding AWGN with a distribution mean ranging from 0.1 to 1. For each distribution mean, we have calculated the differences between the color shift vectors of the pre-processed color 2D barcode sample images versus those of the camera phone captured images. The average differences in the YCbCr movements between our pre-processed sample images and our camera phone captured sample images is presented in Figure 8. The maximum differences in YCbCr movements between our pre-processed sample images and our camera phone captured sample images is presented in Figure 9.

From Figures 8 and 9, we have found that by pre-processing our 2D barcode sample images with an AWGN with a mean of 0.3 give us resultant JPEG sample images that are closest to our camera phone captured sample images. Thus, for the experiments in this paper, an AWGN channel with a distribution mean of 0.3 can closely model this camera phone capture channel for our color 2D barcode.

A visual comparison between this pre-processed sample image against its camera phone captured equivalent is presented in Figure 10.

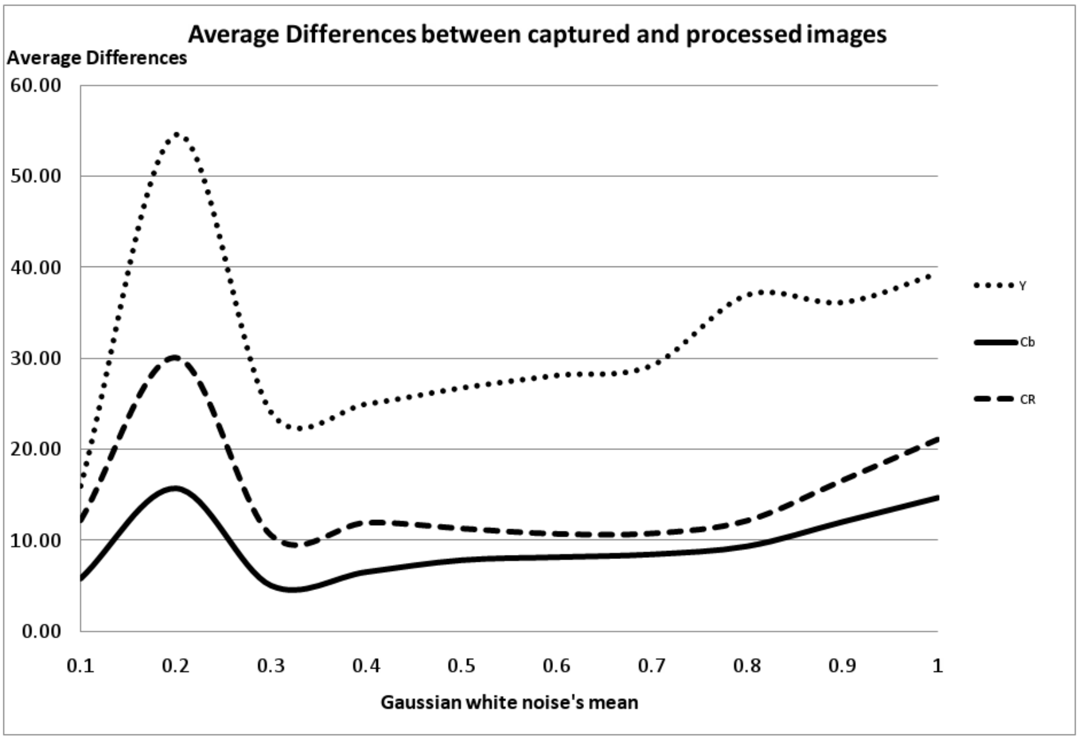


Figure 8. Average differences in *YCbCr* values between our pre-processed sample images and our camera phone captured sample images.

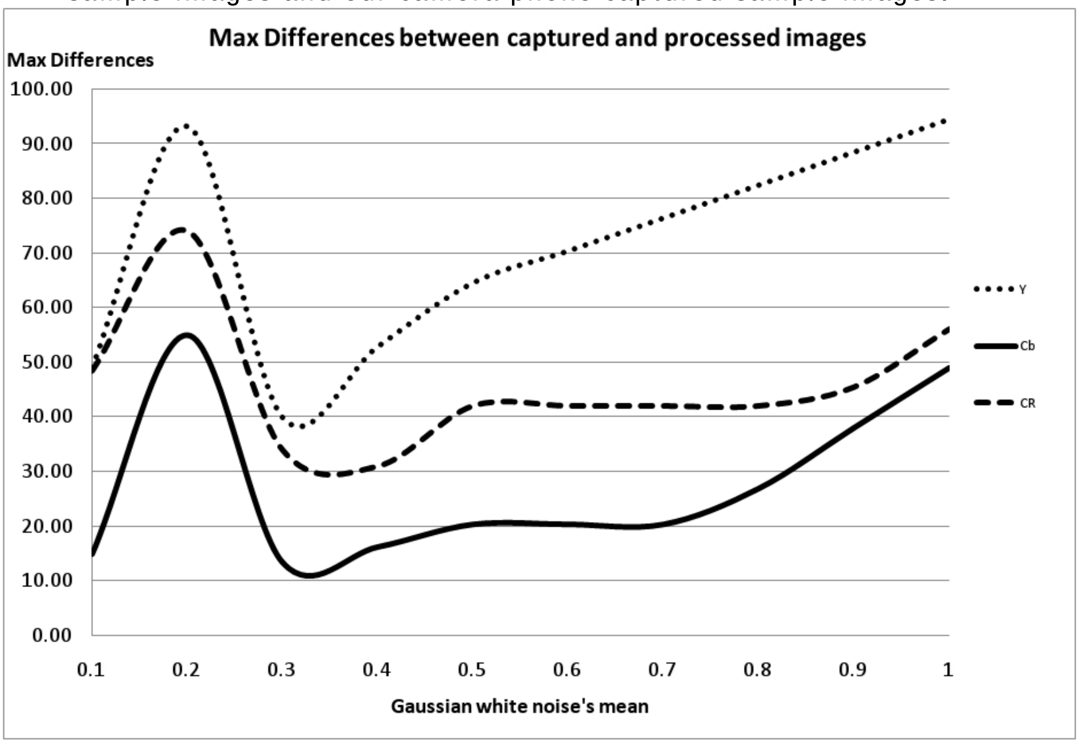


Figure 9. Maximum differences in *YCbCr* values between our pre-processed sample images and our camera phone captured sample images.

## 4. Conclusion

Color 2D barcodes are new emerging pervasive interfaces for camera phones. Nonetheless, using a greater multitude of colors introduces errors that can negatively affect the robustness of barcode reading. Furthermore, most camera phones capture and store such color 2D barcode images in the JPEG format. As a lossy compression technique, JPEG also introduces a fair amount of error in the decoding of captured 2D barcode images. This JPEG quantization error is further compounded by the error introduced by the camera phone capture channel. Thus, robust decoding of color 2D barcode JPEG images is a very challenging task. Hopefully, the work presented in this paper can help to address some of these challenges. From our results herein, we have concluded that a likely model to model the camera phone capture channel errors for color 2D barcodes captured by camera phones and stored in JPEG format is the AWGN channel. With this knowledge, coupled with our work [6] in improving the decompression of JPEG barcode images, it is likely that we will be able to improve the decoding of color 2D barcode images for camera phones.

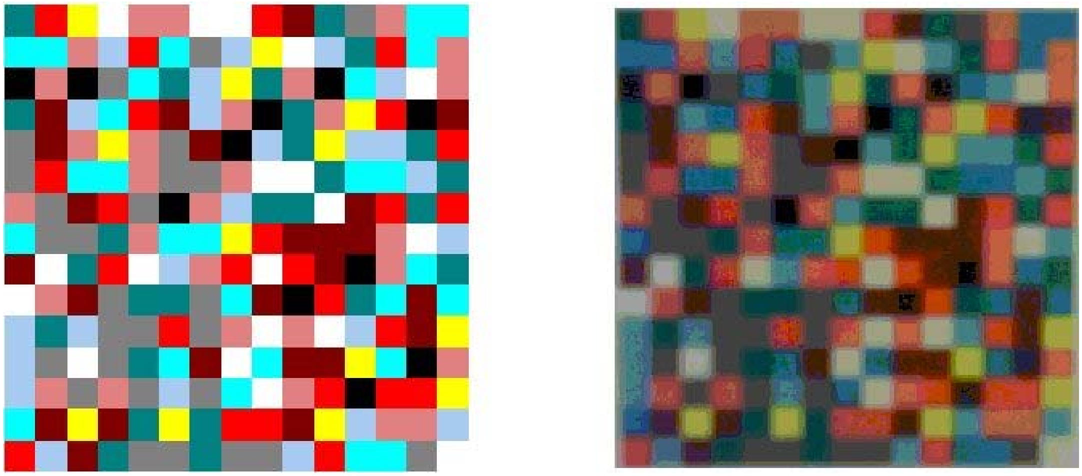

Figure 10. Comparing between a pre-processed 2D barcode sample image (left) and its camera phone captured equivalent (right).

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