Embedding Two-Dimensional Barcodes Into Graphics

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Abstract

Barcodes are typically printed as independent entities in a document, separated from other objects such as pictures, text, graphics, and logos. However, embedding barcodes into these objects aesthetically could make the document more appealing. This paper presents a method to embed a 2-D barcode into a logo-type graphical element by formulating the barcode embedding as a constrained optimization problem. The objective is to maximize the image appealingness while satisfying the minimum symbol contrast requirement for the barcode. It is achieved by constructing a barcode gamut and exploiting existing gamut mapping algorithm to minimize the color appearance difference between the original and barcode-embedded logo-type images.

1. Introduction

Color Quick Response (QR) codes [1] and other two dimensional (2-D) barcodes have become a widely accepted method for storing information which could be easily decoded at high speed. The barcodes can be embedded in official documents such as certificates and diplomas and then be used to verify the authenticity of the documents. Each document has its own QR code assigned with its unique authentication data, which could be retrieved by scanning the barcode and used for the validation of the document and its holder.

Barcodes are typically printed as independent entities on a page, separated from other objects such as pictures, texts, graphics, and logos. However, embedding QR codes into other objects, such as logos and seals, may sometimes make the QR code and the entire document aesthetically more appealing.

A color QR code that resembles a simple logo-type graphic element can be easily generated using a naïve approach by simply combining the graphic colors of the logo with the black and white colors of the barcode. The graphic color is used to replace either black or white color in the barcode, depending on the lightness of the graphic color. The naïve approach illustrated in Figures 1 and 2, where Figure 1 is an example of a barcode to be embedded, Figure 2(a) is an example of a simple logo and Figure 2(b) is the resulting logo with the embedded barcode. The white cells are substituted with yellow color since the graphic yellow color is relative light, and black cells remain intact, as shown in the left half of Figure 2(b). On the other hand, for a relatively dark blue color, only the black cells are changed, as shown in the right half of Figure 2(b).

Figure 1 *An example of a QR code*

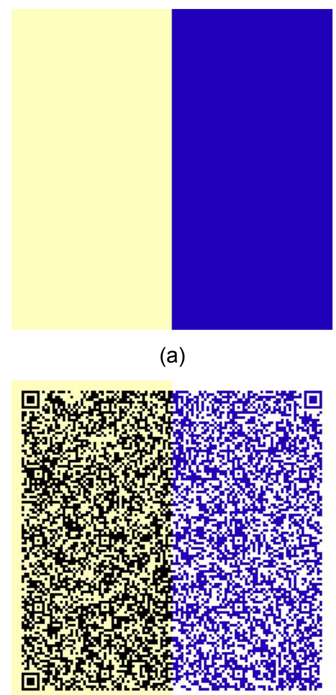
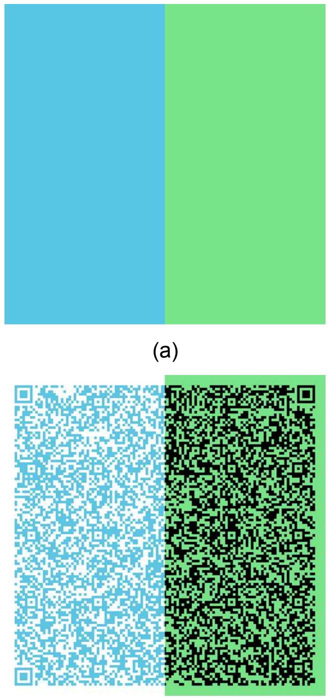


Figure 2 *The naïve approach of embedding QR code into a logo image (a) original logo image (b) resulting logo image with embedded QR code*

There are several limitations for this naïve approach. First, it can not ensure the symbol contrast and hence the readability of the resulting barcode. This will be further explained in the next several paragraphs. Second, the method usually sacrifices too much in image quality, particularly in color saturation. Third, it may result in "brightness reversal". This is illustrated in Figure 3, where Figure 3(a) is the original logo image, and Figure 3(b) is the one embedded with the barcode specified in Figure 1. The left half is slightly darker in the original image, but it becomes much brighter after the embedding.



(a)

(b)

Figure 3 *An example of "brightness reversal" using the naïve approach of embedding QR code into a logo image (a) Original logo image (b) Resulting logo image with embedded QR code*

Suppose a QR code is generated with two colors, a darker color d, and a brighter background color b, the symbol contrast SC is specified in the references [2, 3] as

$$SC = R(b) - R(d) \quad (1)$$

where $R(x)$ is the reflectance value of color x. The symbol contrast grade is determined by

$$4.0\ (\mathrm{A})\ \text{if}\ SC \geq 0.7$$

$$3.0\ (\mathrm{B})\ \text{if}\ SC \geq 0.55$$

$$2.0\ (\mathrm{C})\ \text{if}\ SC \geq 0.4$$

$$1.0\ (\mathrm{D})\ \text{if}\ SC \geq 0.2$$

$$0.0\ (\mathrm{F})\ \text{if}\ SC < 0.2 \quad (2)$$

The symbol contrast is one of the most important parameters for measuring the code readability. It is usually a design parameter determined by each specific application. In this paper, it is treated as a user-defined parameter and will not be optimized jointly with other parameters.

Given a color QR code whose dark and bright cells are generated with a dark color set of N colors, $D = \{d_1, d_2, \ldots, d_N\}$, and a bright color set of M colors, $B = \{b_1, b_2, \ldots, b_M\}$, respectively, Eq. (3) has be satisfied in order to achieve the required symbol contrast Δ,

$$R(b_{\min}) - R(d_{\max}) \geq \Delta \quad (3)$$

i.e., the difference between the minimum reflectance value of the bright color set and the maximum reflectance value of the dark color set should be greater than the required symbol contrast. Let's take the color barcode shown in Figure 3(b) as an example. The bright color set has two colors: white (in the left half) and green (in the right half), while blue and black colors in the dark color set. According to Eq. (3), the symbol contrast is the difference of reflectance value between green (the minimum of the bright color set) and blue (the maximum of the dark color set). Apparently, its symbol contrast is limited, and thus the barcode is difficult to decode.

In this paper, a new method is proposed to efficiently and aesthetically embed a 2-D barcode into a logo type graphical element. The proposed method is compatible with the standard barcode encoding and decoding technologies. Specifically, the resulting barcodes are readable by most standard scanners, including both laser and imaging readers. Although the method is focused on the QR code, it is extensible to other barcodes, such as Data Matrix [4]. The proposed method formulates the barcode embedding as a constrained optimization problem. It attempts to achieve the best image quality while ensuring the code readability by maintaining a sufficient symbol contrast.

The rest of the paper is organized as follows. Section 2 formulates the QR code embedding as an optimization problem. Section 3 provides details of the proposed algorithm. Section 4 shows some experimental examples, and Section 5 draws some conclusions.

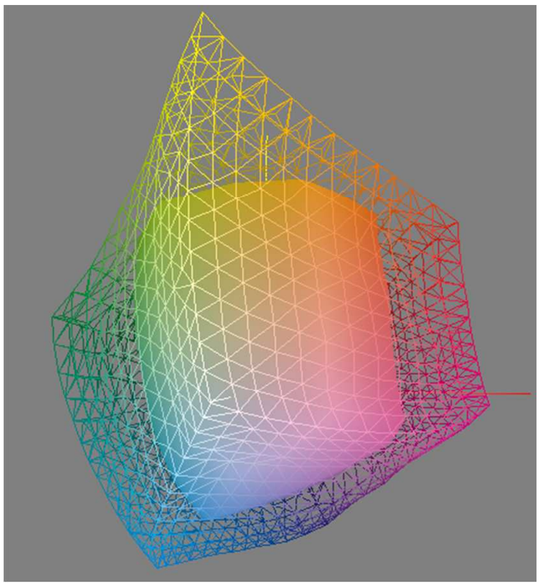
2. Problem Formulation

A QR code is rendered with a pair of colors b_i (for bright cells) and d_i (for dark cells). When viewed from a distance, the QR code is perceived as a mixed color c_i of the pair (b_i, d_i). For most QR codes, which are printed with a relatively low resolution, and contain roughly the same number of dark and bright cells, the perceived color c_i can be reasonably approximated as the average of b_i and d_i assuming that colors are represented in a linear color space.
Most of the graphical images such as logos and seals are composed of regions that are either flat or gradually varying in color. When embedding a QR code into a region with uniform color c_i, we attempt to find a color pair (b_i, d_i), whose average color is the closest to c_i. However, the optimization can not be performed independently for each region. Rather, the overall symbol contrast should satisfy Eq. (3).

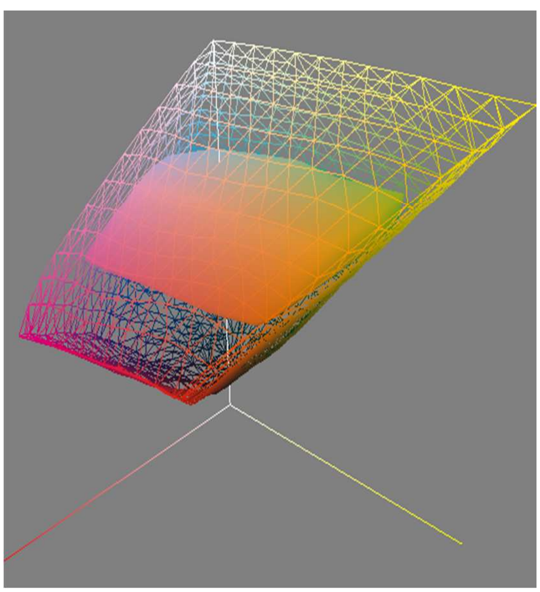
3. Proposed Algorithm

The proposed algorithm is implemented as a double loop. In the outer loop, the higher luminance threshold H is varied, while in the inner loop, the lower luminance threshold L is varied with one constraint, i.e. the difference between H and L should be greater than the required symbol contrast Δ. If $L=H-\Delta$, then only one threshold H is required to be optimized since Δ is defined. These two thresholds naturally divide the printer gamut into three regions, a bright region (luminance above H), a dark region (luminance below L), and a middle region (luminance between L and H). It can be ensured that each color pair (b_i, d_i), where b_i and d_i are picked from the bright and dark regions, respectively, satisfies Eq. (3) or minimum symbol contrast constraint. Thus, the color barcode could be decoded with the standard scanners.

The higher threshold H is optimized to maximize image appealingness of the barcode-embedded logo image while satisfying the minimum symbol contrast constraint. For each threshold H, one image is generated with the proposed approach. Its perceptive image quality is measured against the original logo image. The image with the highest quality measure is selected as the final result. In another implementation, the threshold H is optimized to maximize the volume of the middle region, which is the gamut that could be used to render the barcode-embedded logo image and greatly affects the image quality of the final image.

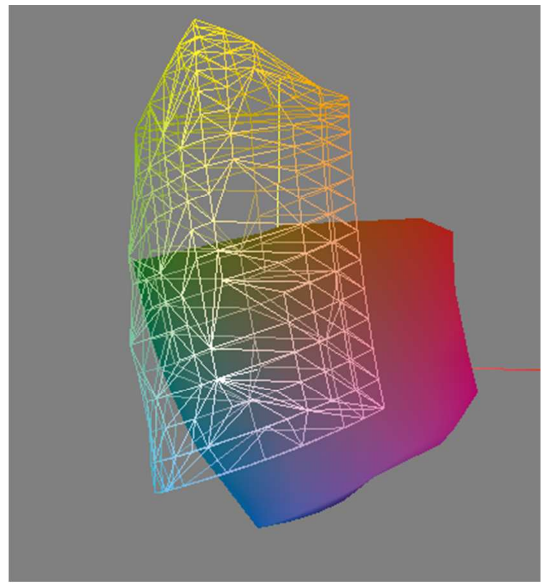


(a) Top View

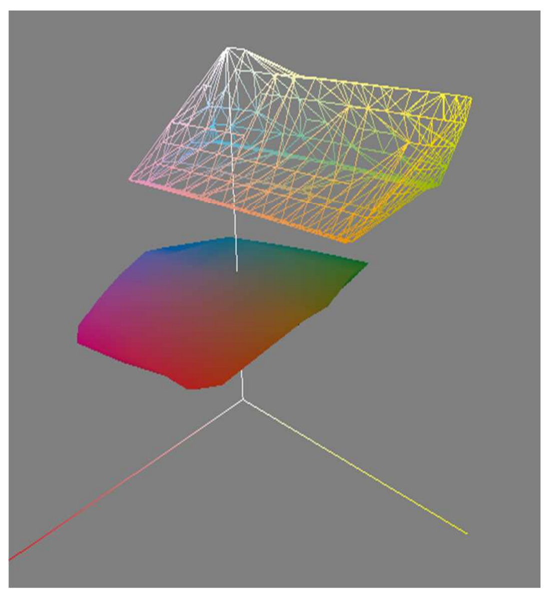


(b) Side View

***Figure 4** Schematic diagram of the middle region (solid) and the entire printer gamut (wired) shown in top view (a) and side view(b).*



(a) Top View



(b) Side View

***Figure 5** Schematic diagram of bottom dark region (solid) and the top bright region (wired) shown in top view (a) and side view(b).*

For each pair (b_i, d_i), where b_i and d_i are selected from the bright and dark regions, respectively, the combined color c_i is calculated as the linear combination of b_i and d_i with equal weights.

$$c_i = 0.5b_i + 0.5d_i \tag{4}$$

The reference [5] gives an example of mixing two illuminants with their spectral distribution known. The middle region consists of all the colors by exhaustively combining colors from the bright and dark regions.

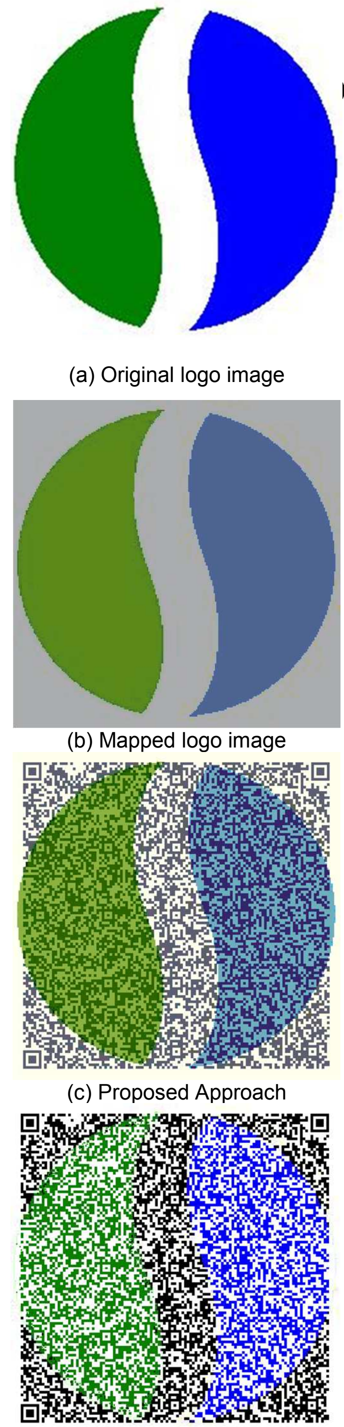
It represents the ensemble of all perceptive barcode colors when viewed from a distance. Thus, it is also called the barcode gamut with all possible colors that could be used for generating color barcodes. This gamut is much smaller than the original printer gamut and contains only its center portion. In other words, it does not include colors that are too saturate, too dark, or too bright. A typical printer gamut (solid) and the barcode gamut (wired) are shown in Figures 4 (a) and (b) with two different views. The bright region (wired) and dark region (solid) are shown in Figures 5 (a) and (b), respectively.

A inverse mapping from c_i to the pair (b_i, d_i) is recorded during the gamut generation process. The mapping is implemented as a lookup table (LUT), whose input is a color c_i, and its output is the correspondent (b_i, d_i) color pair. Since d_i can be determined from c_i and b_i using Eq. (4), only one of them, say b needs to be stored. To generate the LUT, c_i is first quantized to a node in the LUT grid, and color b_i is then recorded for the node. If multiple (b_i, d_i) pairs exist for the same node, the pair with the lowest contrast is stored. If multiple pairs with the same lowest contrast exist, the one with the smallest hue difference is chosen. For the LUT nodes that do not have any corresponding (b_i, d_i) color pairs, their values are obtained from interpolation and extrapolation.

The barcode generation process is as follows. First, the logo image is mapped to the barcode gamut or the middle region to produce a target logo image. Image quality degradation is inevitable here in order to satisfy the minimum symbol contrast constraint. However, the advanced gamut mapping algorithm could alleviate the image quality loss. Many gamut mapping algorithms exist and detailed discussions could be found in the references [6-7]. These algorithms could be implemented in various color spaces, e.g., CIELAB, CIECAM02 or IPT, or with different emphasis, e.g., hue-angle preserving, constant lightness, maximizing saturation, and etc. The algorithm used in this experiment is hue-angle preserving minimum color difference clipping.

The barcode is embedded into the target logo image using the c to b LUT. For each color c_i at each pixel location (x_i, y_i) in the target logo image, the b_i color is obtained from the LUT interpolation. The barcode image is overlaid to cover the target logo image with replications, similar to halftone screening. If the barcode value is zero at (x_i, y_i), the output color for that pixel is b_i, otherwise, the output is d_i, which can be simply calculated.

4. Experimental Result



(a) Original logo image

(b) Mapped logo image

(c) Proposed Approach

(d) Naïve approach

Figure 6 *An example of embedding QR code into a logo image using the proposed approach (c) and the Naïve approach (d).*

Figure 6(a) is an exemplar logo image. The barcode to be embedded is given in Figure 1. Figure 6 (b) is one of the target logo images after gamut mapping. In this example, changing the threshold *H* does not change too much of the image appearance. Figure 6(c) shows the logo with embedded barcode. In comparison, Figure 6(d) was generated using the naïve approach.

5. Conclusions

Barcodes are typically printed as independent entities in a document, separated from other objects such as pictures, text, graphics, and logos. However, embedding barcodes into these objects may sometimes make the barcode and the entire document aesthetically more appealing. A method is proposed to embed a 2-D barcode into a logo-type graphical element by formulating the barcode embedding as a constrained optimization problem. The objective is to maximize the image appealingness while satisfying the minimum symbol contrast requirement for the barcode. The proposed method could render more appealing image than the naïve approach.

References

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Author Biography

Yonghui Zhao received her B. S. and M. S. in material engineering from Dalian University of Technology, China, in 1999 and 2002, respectively. She received her Ph. D. in imaging science from Rochester Institute of Technology, NY, in 2008. She had worked in Xerox Research Center in Webster, NY for about four years. Recently, She joined Apple. Her research interests include color science, digital image processing, machine learning and pattern recognition. She is a member of IS&T and IEEE.