A New Color QR Code Forward Compatible with the Standard QR Code Decoder

Masanori KIKUCHI, Masaaki FUJIYOSHI, and Hitoshi KIYA
Department of Information and Communication Systems, Tokyo Metropolitan University, Hino, Tokyo 191–0065, Japan
Email: kikuchi-masanori@sd.tmu.ac.jp, mfujiyoshi@ieee.org, kiya@sd.tmu.ac.jp

***Abstract*—This paper proposes a new color QR code which is forward compatible with standard QR code decoders for increasing the conveyable capacity of encoded information. The proposed method allocates three standard bicolor QR code to color channels of YC_bC_r color space so that one QR code in the Y channel can be decoded by a standard QR decoder. In addition, a proprietary decoder further decodes two more QR codes in C_b and C_r channels. The proposed method is based on the standard bicolor QR code in its encoding and decoding processes, whereas conventional methods increasing the conveyable capacity require complex proprietary codecs or different technology. Experimental results show the effectiveness of the proposed method.**

***Index Terms*—two-dimensional code, matrix code, color space conversion, color channel-division multiplexing, digital watermark**

I. Introduction

Quick response code (QR code) [1], [2] which was developed mainly to item management in logistics becomes popular in these days [3]–[8] thanks to the spreading of mobile phones with a decoder. QR code is a two-dimensional matrix barcode, and it encodes larger amount of information than the one-dimensional barcode. The conveyable amount of information is designated in accordance with the version, the size of the code, and the version is limited to ten for QR decoders mounted on mobile phones. That is, the information capacity is limited. Several methods have been proposed to increase the capacity [9]–[14], and these methods are classified into two categories; One uses data hiding techniques [9], [10] and the other is based on multilevel intensities [11]–[14].

The former conceals extra information in a standard bicolor QR code by a data hiding technique [9], [10]. Though the data hiding technique slightly distorts the QR code as an image to hide extra data in the code, the distortion by data hiding does not interfere decoding QR codes by a standard QR decoder. A proprietary decoder can decode QR codes and can take out the embedded data. The number of pixels in a QR code should be increased to increase the embeddable extra data, even the version of the QR code is small, because these methods regard QR code as images. Moreover, a proprietary decoder needs a special decoder for hidden data extraction where the special decoder is completely different from a QR code decoder.

The latter which is based on multilevel intensities directly encodes much information [11]–[14] instead of adding extra data to an existing QR code. These methods generates multilevel QR codes, whereas the standard QR code is comprised of bilevel intensities. This category is further classified into two; grayscale and color. The former introduces multilevel intensities to increase the encodable data, but multilevel intensities degrade the tolerance to geometrical transformation and noise. Thus, this approach only doubles the capacity. The latter introduces color variation to further increase the capacity. Colorizing QR codes have been studied from the viewpoint of designing enhancement of QR codes [15]–[18]. Grayscale methods are compliant with the standard QR code, but these coloring methods need a proprietary codec and complex.

This paper proposes a new color QR code which is forward compatible with the standard bicolor QR code. In the proposed method, a standard QR decoder decodes one of three QR codes where each QR code is allocated to a color channel in YC_bC_r color space. A proprietary decoder comprised of color space converter and a standard QR code decoder decodes all three QR codes from a proposed QR code.

II. Preliminaries

This section briefly describes QR code, and conventional multilevel QR codes are reviewed.

A. QR Code

QR code is a two-dimensional matrix code [1], [2] and is superior in the data capacity to the ordinary barcode which is a one-dimensional code thanks to doubling the dimensionality.

A QR code is comprised of small squares referred to as *module*s, where each module is either light (white) or dark (black). QR code has 40 different versions where the number of modules vary according to versions from 21×21 to 177×177 with stepping by 4 modules horizontally and vertically. According to the version, the information capacity is defined.

Reed-Solomon (RS) coding is involved into QR code as a channel coding technique to fight error. Four error correction (EC) levels are defined in QR code, namely, L, M, Q, and H, where 7%, 15%, 25%, and 30% of symbols can be corrected, respectively. The capacity varies in accordance with not only versions but also EC levels.

Figure 1 shows a block diagram of a standard QR code encoder. The encoder first recognizes input data as letters and/or numbers to apply a source coding to the input data. The encoded data are then passed to a RS encoder for the forward EC. Information symbols, parity symbols, and some overhead information are arranged in a QR code by using modules. In addition, the function patterns by which geometrical transformation will be compensated are arranged in the

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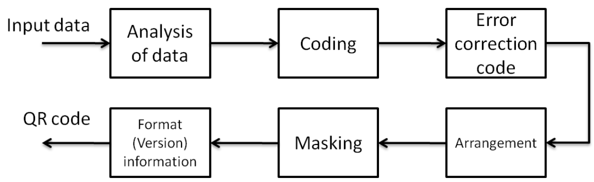


Fig. 1. A block diagram of a standard QR code encoder.

(a) Version 3. (b) Version 10.

Fig. 2. Examples of standard QR codes (error correction level: H).

QR code. To balance light and dark modules for reducing error, eight different masks are applied to the QR code and the one in which light and dark modules are distributed evenly is selected. Finally, version information and information on the used mask pattern are arranged in the QR code to output the final code. Figure 2 shows QR codes of versions 3 and 10 where the EC levels are H for both codes.

Figure 3 shows a block diagram of a standard QR code decoder. By using function patterns, the decoder first detects a QR code from a captured image and compensates geometrical transformation of the code. Modules in the QR code are recognized to take out the version information and the information on the used mask pattern. The QR code is unmasked to extract information symbols and parity symbols. Extracted symbols are decoded by a RS decoder, and the source decoder outputs the decoded information. QR codes are decoded on the basis of these luminance. The threshold to distinguish light and dark modules is given by

$$L = \frac{L_{\max} + L_{\min}}{2}, \qquad (1)$$

where $L_{\max}$ and $L_{\min}$ are the maximum and minimum luminance in a captured image, respectively.

B. Grayscale QR Codes

Instead of bilevel intensities in the standard QR code, multilevel intensities are introduced to QR codes in an improved method to increase the information capacity [11]. Figure 4 shows the intensities for modules where four levels

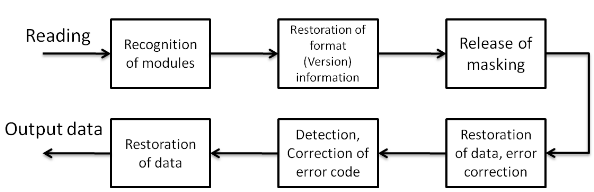


Fig. 3. A block diagram of a standard QR code decoder.

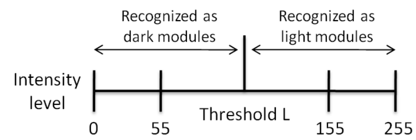
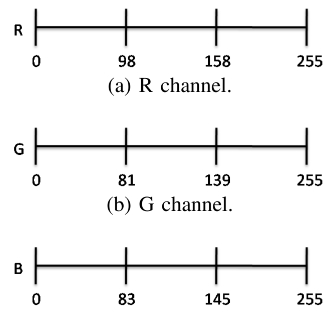


Fig. 4. Example of multilevel intensities for the grayscale QR code [11] (four levels for a 2-bit symbol).



(a) R channel.

(b) G channel.

(c) B channel.

Fig. 5. Example of multilevel intensities for color channels in the conventional color QR code [12].

are assigned. In this method, a standard QR code decoder derives L from a captured image by using Eq. (1) to distinguish light and dark modules, i.e., the standard QR code decoder can take out information from the QR code with multilevel intensities as much as a standard bilevel QR code. A proprietary decoder recognizes four different intensity levels in the QR code, so the doubled amount of information are decoded by using the proprietary decoder. However, the more intensity levels are introduced, the less tolerance against geometrical transformation and error becomes. This method shows that it can increase intensity levels up to four [11].

C. Color QR Codes

The color variation is introduced to QR codes in methods to further increase the information capacity [12], [13]. Similar to the grayscale QR code mentioned in the previous section, multilevel intensities are assigned in each RGB color channel. Figure 5 shows an example of the intensities in RGB color channels where four levels are assigned in each [12].

With the condition shown in Fig. 4, 64 different colors can be represented. Since it is quite difficult for even the proprietary decoder to distinguish 64 different colors in a practical environment, these methods cannot assign a grayscale QR code to each color channel. Instead, a set of colors which can be distinguished from each other is picked up from 64 colors to form a color QR code. It was reported that this approach increases the information capacity up to four times by using 16 colors [14]. By introducing further complex rules to arrange a color set, the color QR code becomes forward compatible with standard QR code decoders [14], but the method needs a proprietary encoder which takes into account color combination, i.e., it needs the encoder totally different from a standard QR code encoder.

III. Proposed Method

This section proposes a new color QR code, which is forward compatible with a standard QR code decoder and is based on the standard bicolor QR code, to increase the information capacity. The proposed method multiplexes three bicolor QR codes by a color channel-division multiplexing, i.e., each color channel has a bicolor QR code independently in this method. To ensure that a standard QR code decoder decodes one QR code in a multiplexed color QR code, the proposed method allocates QR codes in the YC_bC_r color space instead of the RGB color space. A proprietary decoder decodes all QR code in color channels on the basis of a decoding process for standard bicolor QR codes.

A. Encoding

A color QR code is produced by the following algorithm in the proposed method.

Step 1 Divide input data to three portions, and three standard bicolor QR codes are generated by using a standard QR code encoder c.f., Fig. 6. Note versions and EC levels can differ among three QR codes.

Step 2 Select two intensity levels for dark and light modules in each color channel of the YC_bC_r color space; (Y_1, Y_2), (C_{b1}, C_{b2}), and (C_{r1}, C_{r2}). Set the intensity level of dark and light modules to Y_1 and Y_2, respectively, in the Y channel. Similarly, intensity levels for modules are set in C_b and C_r channels. Note the strategy and definitive way to select intensity levels are described in Sect. III-D.

Step 3 Three QR codes in the YC_bC_r color space are converted into the RGB color space. The color conversion in this paper consists of the three equations [19] below;

$$\begin{cases} R = 1.164(Y-16) + 1.596(C_r - 128), \\ G = 1.164(Y-16) - 0.391(C_b - 128) \\ \qquad\qquad\qquad -0.813(C_r - 128), \\ B = 1.164(Y-16) + 2.018(C_b - 128). \end{cases} \tag{2}$$

With this conversion, intensities can vary between 16 and 255 in Y channel and those can vary between 16 and 240 in C_b and C_r channels. In the RGB color space, intensity covers from zero to 255 in all R, G, and B channels.

Figure 6 shows an example of QR codes provided by the above mentioned algorithm. The version and EC levels are 3 and H, respectively, in all Y, C_b, and C_r channels.

B. Decoding

A color QR code is decoded by a standard QR code decoder as well as a proprietary decoder.

1) By a Standard QR Code Decoder:

Step 1 A color QR code is captured and is decoded by a standard QR code decoder as shown in Fig. 3. The bicolor QR code in the Y color channel is decoded by a standard QR code decoder.

(a) Y channel. (b) C_b channel. (c) C_r channel.

(d) A color QR code.

Fig. 6. An example of colored QR code and its components by the proposed method.

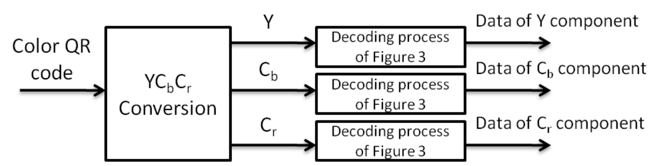


Fig. 7. A block diagram of a proprietary decoder in the proposed method. The decoder consists of a color space converter and standard QR code decoders.

2) By a Proprietary QR Code Decoder:

Step 1 A color QR code captured by a color imaging device in the RGB color space is converted to the YC_bC_r color space. The color conversion is comprised of the following three equations

$$\begin{cases} Y \;= 0.257R + 0.504G + 0.098B + 16, \\ C_b = -0.148R - 0.291G + 0.439B + 128, \\ C_r = 0.439R - 0.368G - 0.071B + 128, \end{cases} \tag{3}$$

where these equations correspond to Eq. (2).

Step 2 Separate color channels into three different channels, namely, Y, C_b, and C_r.

Step 3 Decode the bicolor QR code in each color channel by using a standard QR code decoder.

This algorithm is summarized as Fig. 7.

C. Features

This section summarizes three main features of the proposed method, viz.,

(a) Forward compatible with standard QR decoders,
(b) Improved information capacity,
(c) Highly feasible because of the use of the fundamentals of the standard QR code.

The proposed method is forward compatible with existing standard QR code decoders. That is, a standard QR code decoder partially decodes the proposed color QR code. The standard bicolor QR code in the Y color channel is directly decoded by the standard QR code decoder, because standard QR code decoders only use the luminance of captured images and the chrominance such as C_b and C_r color channels are ignored. Since the QR code in the Y color channel is a standard QR code, the amount of information decoded by a standard QR code decoder is the same as the amount of information conveyed by a standard QR code. It is noted conventional color QR codes did not take into account the forward compatibility with standard QR code decoders sufficiently well, whereas the proposed method designs a new color QR code with fully taking into account the compatibility. This feature of the proposed method is expected to open a new vista of applications and makes the proposed method widely used.

The proposed method can encode information in a color QR code three times as many as the standard bicolor QR code. The proposed color QR code is superior in the information capacity to grayscale QR code which increases the capacity twice to the standard QR code [11]. Whereas conventional color QR code increases the capacity more than three times by introducing multilevel intensities, the proposed method does not introduce them to value the last feature of the proposed method described below. It is noted that introducing multilevel intensities to the proposed method can increase the capacity much more.

The proposed method essentially multiplexes three standard bicolor QR codes into one color QR code. Thus, the method requires an extra color space conversion, but it is all the proposed newly introduced. Encoding and decoding QR codes are provided by standard QR code codec. Therefore, the proposed method enjoys standard QR code's tolerance against geometrical transformation and noise.

Moreover, three standard QR codes can be totally different from each other in versions and EC levels. With this feature, an unequal importance information transmission is achieved. That is, the most important portion of information is encoded as the QR code in the Y color channel, because standard QR code decoder can decode it from the proposed color QR code. On the other hand, QR codes in C_b and C_r color channels transmit supplement information.

D. Intensity Levels for Light and Dark Modules

The proposed method selects intensity levels for light and dark modules in each color channel, as shown in Fig. 8. This section describes the strategy and algorithm to determine the intensity levels, $\{\ (Y_1,Y_2),\ (C_{b1},C_{b2}),\ (C_{r1},C_{r2})\ \}$.

The distance between intensity levels in each color channel,

$$\Delta Y = Y_2 - Y_1, \tag{4}$$

$$\Delta C_b = C_{b2} - C_{b1}, \tag{5}$$

$$\Delta C_r = C_{r2} - C_{r1}, \tag{6}$$

are expected to be set as large as possible to distinguish light and dark modules accurately. However, the proposed method does not set Y_1 to the minimum value, 16, nor Y_2 to the maximum value, 235. Converted intensities in the RGB color space are clipped to [0,255] for eight-bit images, and this clipping changes reconverted intensities in the Y channel from those original values. That is, Y_1 and Y_2 in an encoding process are different from those in a decoding process. It results in introducing decoding error to the proposed method. So the requirements for intensity levels are summarized as:

- Converted intensities in the RGB color space are in [0,255],
- Set ΔY, ΔC_b, and ΔC_r as large as possible.

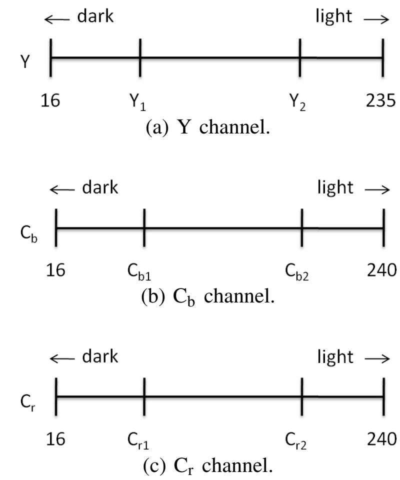


Fig. 8. Intensity level assignment in color channels in the proposed method.

From now, the strategy and algorithm satisfying the above mentioned requirements are developed. Eqs. (2) and (3) define the spanned subspace in the YC_bC_r color space where all points in the subspace are always converted into the subspace spanned over [0,255] in each color component in the RGB space. Figure 9 shows cross-sectional surfaces of the practical subspace spanned in the YC_bC_r color space at various Y's. Two diagonal vertexes of a rectangle within the surface are (C_{b1},C_{b2}) and (C_{r1},C_{r2}) under the designated Y, and ΔC_b and ΔC_r are given by (C_{b1},C_{b2}) and (C_{r1},C_{r2}). Note the shape and size of the surface vary according to Y and that many rectangles exist in the surface, e.g., two rectangles are shown in Fig. 9 (a), where rectangle 1 makes ΔC_b large and ΔC_r small and rectangle 2 enlarges and balances ΔC_b and ΔC_r.

Figure 10 plots possible C_{b1}'s, C_{b2}'s, C_{r1}'s, and C_{r2}'s for various Y's, where ΔC_b and ΔC_r are set as large as possible and are balanced, c.f., rectangle 2 in Fig. 9 (a). The algorithm is developed as follows based on the strategy derived here.

Step 1 Determine desired ΔY, and select Y_1 and $Y_2 = Y_1 + \Delta Y$.

Step 2 Derive (C'_{b1},C'_{b2}) and (C'_{r1},C'_{r2}) which correspond to selected Y_1. Similarly, (C''_{b1},C''_{b2}) and (C''_{r1},C''_{r2}) which correspond to selected Y_2 are derived. See Fig. 10.

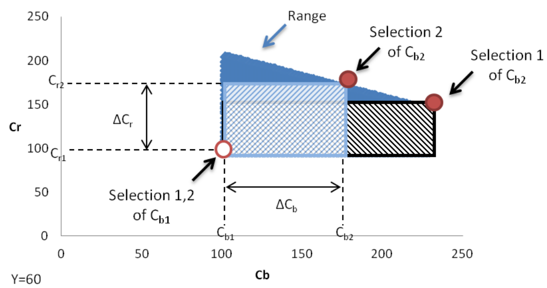
Step 3 Compute ΔC_b and ΔC_r by

$$\Delta C_b = \max\{C'_{b1},C''_{b1}\} - \min\{C'_{b2},C''_{b2}\}, \tag{7}$$

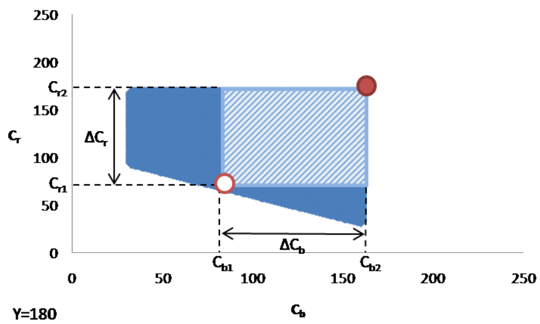
$$\Delta C_r = \max\{C'_{r1},C''_{r1}\} - \min\{C'_{r2},C''_{r2}\}. \tag{8}$$

Step 4 If ΔC_b and ΔC_r are acceptable, exit this algorithm. Else, choose different ΔY or Y_1 and back to Step 2.

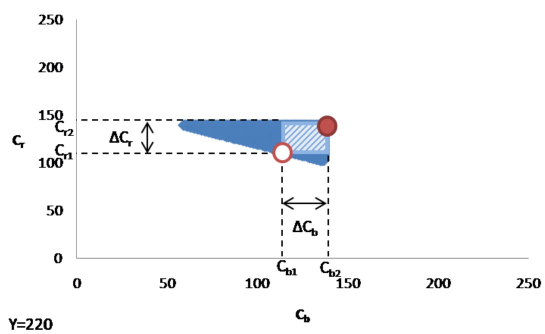
The next section gives a tangible setting of these parameters.



(a) Y = 60.

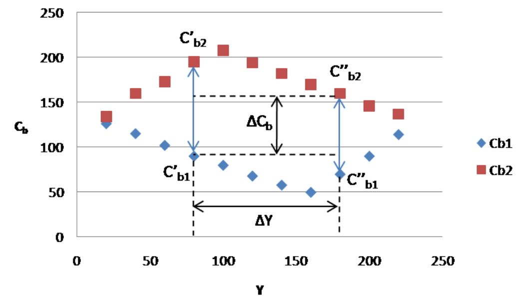


(b) Y = 180.

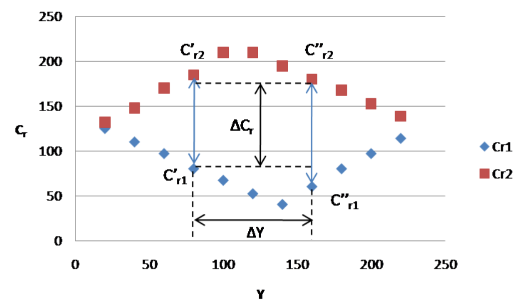


(c) Y = 220.

Fig. 9. Ranges of Y, C_b, and C_r components for guaranteeing practical RGB values.



(a) C_b corresponding to Y



(b) C_r corresponding to Y

Fig. 10. C_b and C_r values determined in accordance with Y value.

TABLE I
CONDITIONS FOR EVALUATION.

Acquired environment	Under white fluorescent
Display	Princeton PTFWHF-19W
Printer	KONICA MINOLTA magicolor 1650EN
Printing paper	Plain paper
Acquisition device	iPhone4S (8 million pixels, CMOS)
Saving format	BMP
Version	3
Error correction level	H (30%)
Print size of one side	4cm
decoder1	Qrafter (Karem Erkan) [20]
decoder2	ICONIT (MEDIASEEK Inc.) [21]
decoder3	QR Code Decode Library (Psytec Inc.) [22]

IV. EXPERIMENTAL RESULT

The proposed color QR codes were captured by a camera device and decoded for evaluating the performance.

A. Conditions

The performances were evaluated in the environment summarized in Table I. The proposed color QR codes were displayed on a monitor and printed on a sheet. Three standard decoders are involved into the evaluation.

B. Forward Compatibility with a Standard QR Decoder

This section evaluates the forward compatibility of the proposed color QR code with standard QR code decoders. Three sets of intensity levels for light and dark modules listed in Table II were derived by the algorithm described in Sect. III-D and used. Set (a) values QR codes in C_b and C_r color channels instead of that in Y channel. Set (b) values the importance of color channels equally. Set (c) gives higher priority to QR codes in Y and C_r channels.

Table III summarizes results where QR codes are displayed on a monitor and are printed on a sheet. It was confirmed that the QR code in the Y channel of the proposed color QR code is decoded by standard QR code decoders as large as ΔY is large enough to be decoded. That is, the proposed method is forward compatible with standard QR code decoders.

C. Effectiveness of the Proposed Color QR Code

This section evaluates the decoding performance of the proposed color QR codes; decoding all bicolor QR codes

TABLE II
INTENSITY LEVEL SETS FOR EVALUATION.

Intensity sets	(Y_1,Y_2), ΔY	(C_{b1},C_{b2}), ΔC_b	(C_{r1},C_{r2}), ΔC_r
(a)	(120, 160), 40	(68, 170), 102	(60, 180), 120
(b)	(60, 160), 100	(102, 170), 68	(97, 170), 73
(c)	(80, 180), 100	(100, 160), 60	(82, 170), 88

TABLE III
DECODING PERFORMANCE OF ONE QR CODE FROM COLORED QR CODES CAPTURED FROM PAPERS AND FROM A SCREEN BY STANDARD QR DECODER SOFTWARE (○: SUCCESS AND ×: FAILURE).

	Printed on a sheet			Displayed on a monitor		
	Intensity sets			Intensity sets		
	(a)	(b)	(c)	(a)	(b)	(c)
decoder1	×	○	○	×	○	○
decoder2	×	○	○	×	○	○
decoder3	×	○	○	×	○	○

(a) Y channel. (b) C_b channel. (c) C_r channel.

Fig. 11. Binarized images in set (b) by discriminant analysis method [23].

in Y, C_b, and C_r color channels. The proposed color QR codes were printed on a sheet and captured by a camera. The captured code in the RGB color space was converted into the YC_bC_r color space, and the grayscale images were binarized by the discriminant analysis method [23] in each color channel. Figure 11 shows binarized images in set (b).

Table IV shows the results when binarized codes were (captured by a camera for decoders 1 and 2 and) decoded. It was confirmed that QR codes in C_b and C_r color channels can be decoded under the condition that set (a) is used. Similarly, it was confirmed that QR codes in Y and C_r color channels can be decoded with set (c). The results for set (b) showed that intensity level sets exist which makes all QR codes in Y, C_b, and C_r color channel decodable.

It is concluded that the proposed method multiplexes three information to a color QR code and that all QR codes in each channel can be decoded. It is shown that designing intensity level sets where two QR codes have higher priority than the remaining QR code is available.

V. CONCLUSIONS

This paper has proposed a new color QR code in which three different standard bicolor QR codes are assigned to Y, C_b, and C_r color channel. The proposed method encodes information three time as much as the standard QR code, whereas the method is forward compatible with standard QR code decoder by involving the YC_bC_r color space instead of the RGB color space. Practical intensity level sets for light and dark modules in QR codes was investigated by focusing the color space conversion, and the algorithm to determine the intensity level set was developed. It was confirmed by using multiple QR code decoders that the proposed color QR code can be decoded regardless of being on a monitor or a sheet.

Further works include the sophistication of the algorithm for intensity level sets determination and introducing multilevel intensities to the proposed method.

TABLE IV
DECODING PERFORMANCE OF THREE QR CODES IN COLORED QR CODES CAPTURED FROM PAPERS (○: SUCCESS AND ×: FAILURE).

	Results (Y, C_b, C_r)		
	Intensity set (a)	Intensity set (b)	Intensity set (c)
decoder1	(×,○,○)	(○,○,○)	(○,×,○)
decoder2	(×,○,○)	(○,○,○)	(○,×,○)
decoder3	(×,○,○)	(○,○,○)	(○,×,○)

REFERENCES

[1] ISO/IEC, "Information technology – Automatic identification and data capture techniques – QR code 2005 bar code symbology specification," IS 18004:2006, 2006.
[2] ISO/IEC, "Information technology – Automatic identification and data capture techniques – Data matrix bar code symbology specification," IS 16022:2006, 2006.
[3] S.K. Ong, D. Chai, and A. Rassau, "The use of alignment cells in MMCC barcode," in *Proc. IEEE ISCIT*, 2010, pp.640–645.
[4] H.-C. Huang, F.-C. Chang, and W.-C. Fang, "Reversible data hiding with histogram-based difference expansion for QR code applications," *IEEE Trans. Consum. Electron.*, vol.57, pp.779–787, Jul. 2011.
[5] L.F.F. Belussi and N.S.T. Hirata, "Fast QR code detection in arbitrarily acquired images," in *Proc. SBC Conf. Graphics, Patterns and Images*, 2011, pp.281–288.
[6] D. Conde-Lagoa, E. Costa-Montenegro, F.J. Gonzalez-Castao, and F. Gil-Castineira, "Secure eTickets based on QR-Codes with user-encrypted content," in *Proc. IEEE ICCE*, 2010, pp.257–258.
[7] M. Shimizu, M. Fujiyoshi, and H. Kiya, "No reference Affine compensation using three 2-D barcodes," in *Proc. IEEE ISCIT*, 2010, pp.634–639.
[8] T. Hiroi, M. Fujiyoshi, and H. Kiya, "Augmented reality using multiple barcodes," in *Proc. IEICE/ITE/KSBE IWAIT*, 2011.
[9] S. Rungraungsilp, M. Ketcham, V. Kosolvijak, and S. Vongpradhip, "Data hiding method for QR code based on watermark by compare DCT with DFT domain," in *Proc. IEEE ICCCT*, 2012, pp.144–148.
[10] S. Ono, M. Tsutsumi, and S. Nakayama, "A copy detection method for colored two-dimensional code using digital watermarking," *IEICE Trans. Inf. & Sys. (Japanese Edition)*, vol.J94-D, pp.1971–1974, Dec. 2011.
[11] K. Furumoto, Y. Watanabe, and M. Morii, "Gray scale two-dimensional code and its applications," *IEICE Tech. Rep.*, vol.112, no.315, ICSS2012-46, pp.7–12, Nov. 2012.
[12] Y. Endo, R. Onga, M. Hiromoto, and M. Morii, "Proposal and evaluation of a multiplexed color QR code," *IEICE Tech. Rep.*, vol.109, no.205, LOIS2009-25, pp.43–48, Sep. 2009.
[13] S. Sukegawa, M. Ito, K. Kondo, T. Ozono, and T. Shintani, "A high capacity multicolored 2D barcode based on QR code," in *Proc. 70th IPSJ National Convention*, pp.4-845–4-846, Mar. 2008.
[14] N. Teraura and S. Kouichi, "On correcting the cell level error of the two-dimensional code with encryption and compatibility," in *Proc. IEICE SCIS*, Jan. 2013.
[15] M. Bao, M. Fujiyoshi, and H. Kiya, "Multi-functionalization of QR codes by introducing color information," *ITE Tech. Rep.*, vol.36, no.39, ME2012-117, pp1–4, Oct. 2012.
[16] M. Kikuchi, M. Fujiyoshi, and H. Kiya, "A method of overlaying color images on QR codes," in *Proc. IEICE General Conf.*, p.A-97, Mar. 2013.
[17] A·T Communications, Co., Ltd., "LogoQ," http://logoq.net/logoq/, 2007.
[18] M. Hagiwara, "QR-JAM," http://staff.aist.go.jp/hagiwara.hagiwara/ qr-jam/, 2010.
[19] Rec. ITU-R BT.601-7, "Studio encoding parameters of digital television for standard 4:3 and wide-screen 16:9 aspect ratios," 2011.
[20] Ali Kerem Erkan, "Qrafter," http://qrafter.com/.
[21] Mediaseek Inc., "ICONIT," http://www.iconit.jp/.
[22] Psytec Inc., "QR code decode library," http://www.psytec.co.jp/product/03/.
[23] N. Otsu, "A threshold selection method from gray-level histograms," *IEEE Tran. Systems, Man, and Cybernetics*, vol.SMC-9, pp.62-66, Jan. 1979.