Sensors and Materials, Vol. 34, No. 5 (2022) 1917–1926
MYU Tokyo

S & M 2942

Printed Aesthetic Quick Response Codes

Yi-Huei Ho,[1] Tzren-Ru Chou,[1] Chun-Shien Lu,[2] and Hsi-Chun Wang[1*]

[1]Department of Graphic Arts and Communications, National Taiwan Normal University,
Da-an District, Taipei City 106010, Taiwan (R.O.C.)
[2]Institute of Information Science, Academia Sinica, Nangang Dist, Taipei City 115201, Taiwan (R.O.C.)

(Received June 30, 2021; accepted May 6, 2022)

Keywords: QR code, output equipment, information hiding

Quick response (QR) codes are currently the most commonly used 2D barcodes. They are composed of black and white modules, which detract from their aesthetic appeal. When printed, owing to the size, dot gain, and other printing conditions, barcode information is easily distorted, yielding poor recognition results. We present a systematic aesthetic QR code information embedding technique as well as an error analysis method for physically printed QR codes. QR code information is embedded in a cover image at different strengths and is then printed using two devices. Barcode information is recognized using a geometric transformation by locating and identifying information dots. We propose an adaptive algorithm that hides barcode information in a cover image given the barcode module identification error characteristics (false blacks and false whites). According to these error characteristics, we adaptively enhance the signal of the white embedded modules to improve the overall recognition ability. The experimental results show that the proposed method is compatible with current printing and output equipment. Judicious adjustment of the embedding strength of white module dots decreases the false-black recognition error caused by dot gain and yields small printed aesthetic QR codes that look better. This improves the decoding rates of aesthetic QR codes. We optimize the QR code embedding method and the reading ability given specified output device conditions. This study highlights the importance of the output conditions for integrated applications of aesthetic QR codes.

1. Introduction

1.1 Background and related work

With the development of computer technology and the popularity of sensing devices such as those in smartphones, quick response (QR) codes, as shown in Fig. 1(a), are now the most commonly used 2D barcode. In recent years, research on QR code technology has gradually increased. Yang *et al.* considered the data capacity of existing QR codes to be insufficient and proposed HiQ,(1) a technique that used color to increase the data capacity of QR codes; however, this code can still be improved visually and is incompatible with current QR readers. Yuan *et al.*

---

[*] Corresponding author: e-mail: hsiwang@ntnu.edu.tw

https://doi.org/10.18494/SAM3491

developed a set of two-layer QR codes that did not require an additional code reader or decoder. The independent messages in two different QR codes were read in different scanning directions on both the left and right sides. They also proposed that, in the future, there should be more than two messages in a QR code and that QR codes should be combined with other beautification methods.(2) Kikuchi *et al.* replaced the black and white modules of QR codes with convex and smooth grooves on a curved surface, respectively, by combining a QR code with 3D printing technology.(3) Zhang *et al.* proposed a method of hiding and protecting QR codes based on multichannel visual masking. In addition to changing the visual appearance of QR codes, their QR code still had a protective function after printing.(4) Numerous technologies and studies on the applications of QR codes have demonstrated that functionality, security, and design are important development trends in current QR code research.

1.2 QR code beautification

Despite the wide use of QR codes, they are not closely integrated in our daily lives. Because QR codes are composed of black and white modules, they are not aesthetically pleasing when integrated in graphics, text, and product advertising applications. Therefore, recent years have seen an increasing focus on beautifying QR codes [Figs. 1(b)–1(e)]. Lin *et al.* proposed an effective two-stage method to generate aesthetic QR codes with high-quality visual content. They designed a rendering mechanism to beautify QR codes without affecting their decodability.(5) Garateguy *et al.* proposed an optimization method that combines a QR code with color images. After inputting a color image, a QR code, and a mask, the local image was encoded independently. A halftone mask was used, and the parallel operation was completed through interpolation to generate an aesthetic QR code based on the image.(6) Wang *et al.* combined two QR codes with images to generate an aesthetic QR code. The explicit QR code was decodable using a smartphone scanner, whereas the implicit QR code could only be detected under IR light. Thus, after photocopying, the implicit QR code no longer existed. This technique combined an aesthetic QR code with anti-counterfeiting features.(7)

1.3 Aesthetic QR code output

Most beautified QR codes are created by processing a digital file; noise caused by printing or outputting the digital file has been rarely mentioned in previous studies. However, the output

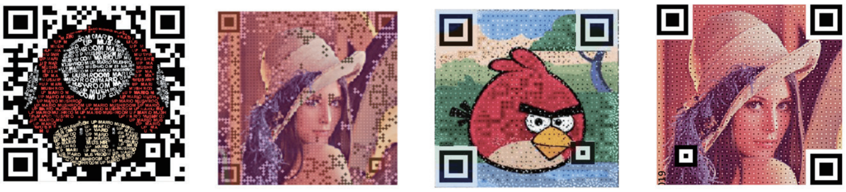
(a) (b) (c) (d) (e)

Fig. 1. (Color online) QR code and beautified QR codes in related research.

quality of aesthetic QR codes in printed formats determines whether they can be used for commercial applications. When an aesthetic QR code is printed, the barcode information is easily distorted due to the size, dot gain, and other printing conditions, which affect decoding and recognition. The aesthetic QR code generated in this work is 492 × 492 pixels for an output resolution of 600 dpi (with a physical size of 2.1 × 2.1 cm^2). The printed output sizes of aesthetic QR codes in related studies are shown in Fig. 2. Although Hung *et al.* proposed an aesthetic QR code to generate microscopic images, displaying these microscopic images required an output size of approximately 19 cm, which was inconvenient in scanning and applications.(8) Kuribayashi and Morii proposed changing the Reed–Solomon encoding to generate a beautiful QR code without affecting its error correction ability. The output size of their code was about 3.4 cm, which still yielded image artifacts.(9) Garateguy *et al.* proposed an optimization method that combined QR codes with color images, with an output size of about 8 cm.(6) The aesthetic QR code used in this work requires a size of merely 2 cm, allowing it to be applied to many products. The small QR code can be viewed with the eye from a certain distance at an acceptable visual quality, and the information can be read by a QR reader from a closer range.

In this research, to produce an aesthetic QR code that can be read after being printed, and to analyze the quality of the printed images, we output the digital image of the aesthetic QR code at both high and low resolutions. Given a partial magnified digital image of the aesthetic QR code and two print-and-scanned images obtained with different output devices, we observe that the high-resolution output is not as clear as the digital file and the information dots are still visible, whereas the information points in the low-resolution output are blurred and unclear, as shown in Fig. 3.

Owing to the dot gain, white information dots are obscured, which affects decoding and



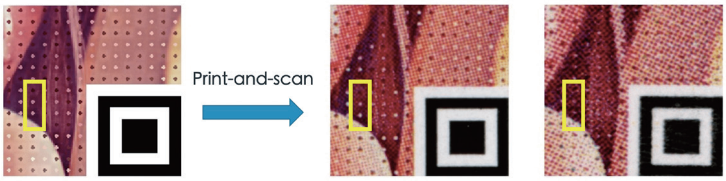
19cm。
Hung *et al.*, 2020

3.4cm。
Kuribayashi & Morii ,2017

8cm。
Garateguy *et al.*, 2014

2.1cm
Graphic QR code
in this research

Fig. 2. (Color online) Printed QR code output sizes in various beautification studies.



Digital Image of
Aesthetic QR code

Print-and-scan image
by digital printer
(High resolution)

Print-and-scan image
by laser printer
(Low resolution)

Fig. 3. (Color online) Close-ups of digital image and print-and-scanned images for different output methods.

recognition. Therefore, in this work, we also enhance the white dots in the image file to improve recognition, as shown in Fig. 4.

1.4 Our contributions

As discussed above, there are a few studies on aesthetic QR code printouts. The contributions of our study are as follows:

1. We show that given the same digital image of the aesthetic QR code, different printing output methods affect decoding and recognition differently.
2. We obtain the optimal method for embedding information in the QR code according to the conditions of the given digital image and the output device.
3. We produce printed aesthetic QR codes that are both aesthetically pleasing and easy to decode; this will facilitate their use for various industrial applications in the future.

2. Materials and Methods

A flowchart of our proposed approach is shown in Fig. 5. The QR code is embedded into the original image to produce an aesthetic QR code, and the digital files are printed and output using a digital printer (high resolution) and a laser printer (low resolution). We scan the two printed images at 1200 dpi to yield print-and-scanned images, and then analyze the module error and codeword error. From the resultant recognition rates, we determine the optimal parameters for the aesthetic QR code using different output devices.

The QR code used in this study is the sixth version, with 41 × 41 modules, 172 codewords (8-bit QR code modules), and the highest level of error correction H (30%). The QR code information is embedded in the cover image to generate an aesthetic QR code with a size of

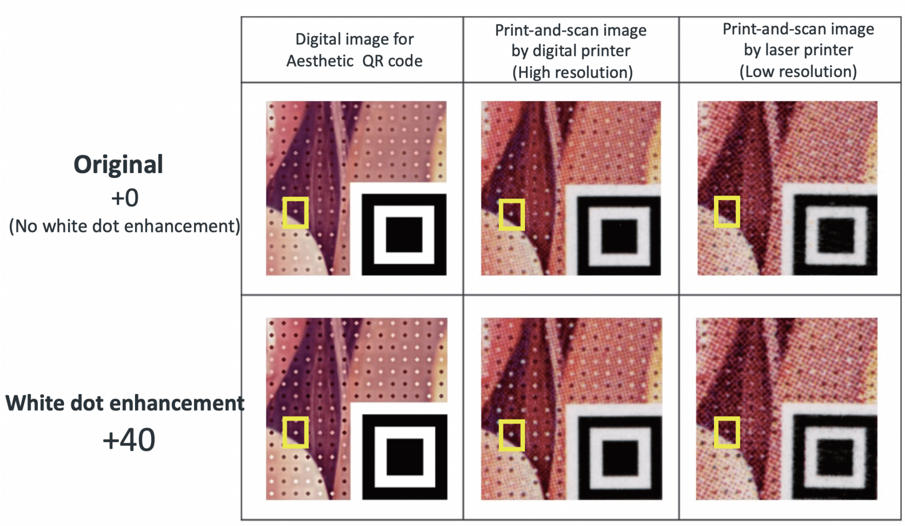


Fig. 4. (Color online) Various output methods for white dot enhancement. Enhancing the white dot by 40 yields a white dot in the yellow box that is more obvious.

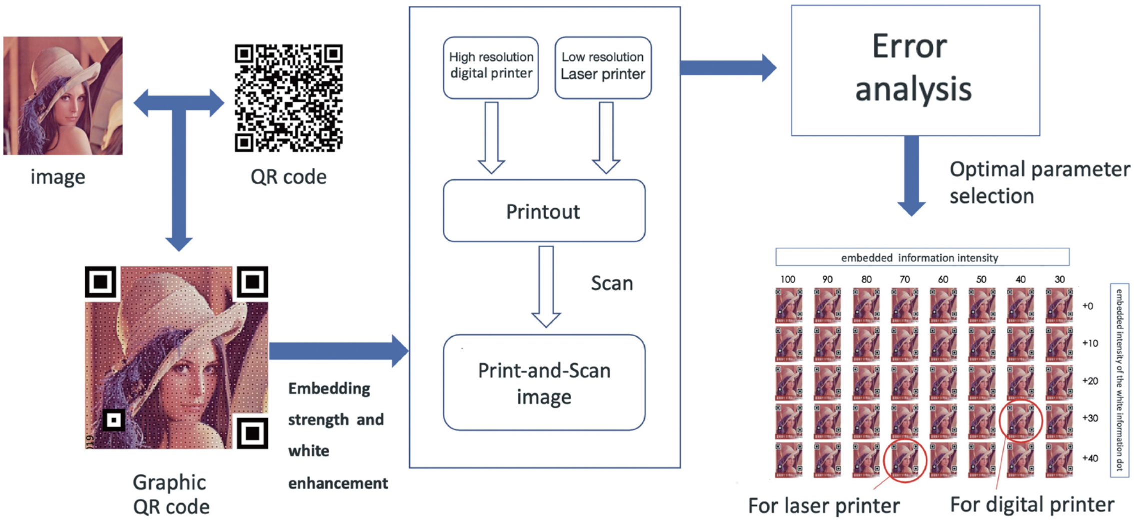


Fig. 5. (Color online) Proposed approach.

492 × 492 pixels. By the method developed by Wang *et al.*,(7) after adjusting the image tone of the cover image, each module is divided into 12 × 12 pixels, with the QR code information placed in the central area (a 4 × 4 square without corner pixels) of 12 × 12 pixels. By an information hiding technique, the QR code information embedded at different information strengths is implanted into the original color image, and the error is diffused to the adjacent pixels for adjustment, as shown in Fig. 6. To ensure that the information dots do not affect recognition after the printing process and to determine the optimal conditions for the output quality of the aesthetic QR code, QR code information at different strengths of 30 to 100 (in grayscale) is embedded into the original cover image, and the white dots are enhanced by 0 to 40 (in grayscale) to produce digital files for the aesthetic QR codes of 40 (5 × 8 format) pieces, as shown in Fig. 7.

The output devices were a Kodak Nexpress 2700 digital printer (high resolution) and a RICOH SP C420DN laser scanner (low resolution). The printed images were scanned using an EPSON PerfectionV600 photo scanner at 1200 dpi, which yielded print-and-scanned images at different information strengths and white-dot-enhanced aesthetic QR code images via different output devices.

The images were further used for error analysis in accordance with the flowchart in Fig. 8. In general, because of the dot gain effect, there are more false blacks than false whites. We used a finder pattern to automatically locate the sampling positions of the aesthetic QR code, and applied a geometrical transformation to extract the correct positions of the aesthetic QR code information dots. The transformation matrix is formulated in Eq. (1): X represents the coordinates of the original QR code as (x_i, y_i), $i = 1, ..., 4$, P represents the corresponding points after the geometric transformation as (p_i, q_i), $i = 1, ..., 4$, and F represents the coefficients a_i and b_i of the transformation matrix ($i = 0, 1, 2$). The simplified representation of Eq. (1) is $P = FX$. Since matrices X and P are known and F is unknown, $F = PX^T (XX^T)^{-1}$ is solved by linear algebra to find F.

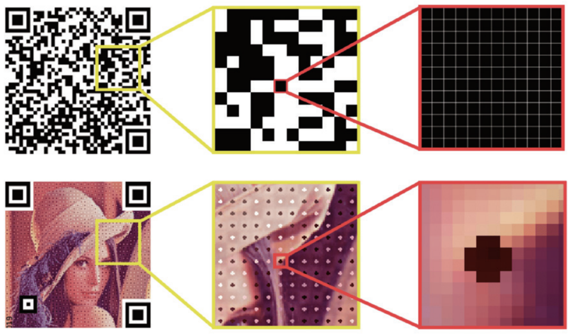


Fig. 6. (Color online) Schematic of information hiding combined with error diffusion.

Fig. 7. (Color online) Embedding of QR code information at different embedding strengths and white dot enhancement levels.

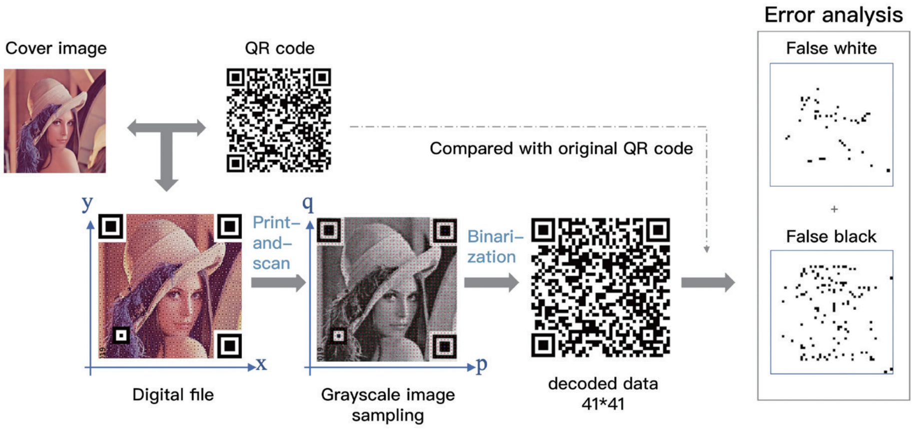


Fig. 8. (Color online) QR code recognition and error analysis.

$$\begin{bmatrix} p_1 & p_2 & p_3 & p_4 \\ q_1 & q_2 & q_3 & q_4 \end{bmatrix} = \begin{bmatrix} a_0 & a_1 & a_2 \\ b_0 & b_1 & b_2 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 & 1 \\ x_1 & x_2 & x_3 & x_4 \\ y_1 & y_2 & y_3 & y_4 \end{bmatrix} \tag{1}$$

The recognized image is converted into a binarized image and compared with the original QR code to calculate the recognition results of the aesthetic QR code's embedded information. The information dot module identification error map of the printed output image is divided into false whites (original black dots recognized as white dots), false blacks (original white dots recognized as black dots), and the codeword error rate correlation. This facilitates the calculation of the optimal parameters of the aesthetic QR code for a specified image given different output devices.

3. Results and Discussion

We outputted the aesthetic QR code embedded with various information strengths and levels of white dot enhancement by various output methods (high resolution and low resolution), after which, we analyzed the module error and codeword error of the aesthetic QR code. We then determined the information embedding strength and white dot enhancement needed to yield the optimal output parameters.

3.1 Error map

Error analysis yielded the error maps shown in Fig. 9, obtained with information embedding strengths of 30 to 100 for (a) high-resolution and (b) low-resolution outputs. The stronger the embedded information, the fewer the errors. Low-resolution outputs produced more errors.

3.2 Module error rate of white enhancement

Figure 10 shows the error analysis results for information embedding strengths from 30 to 100 and white dot enhancements from 0 to 40 for high- and low-resolution outputs. Both output

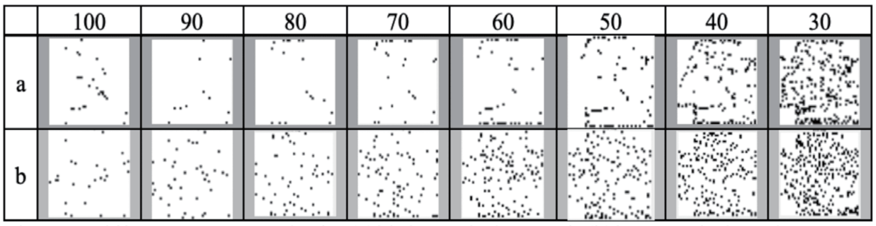
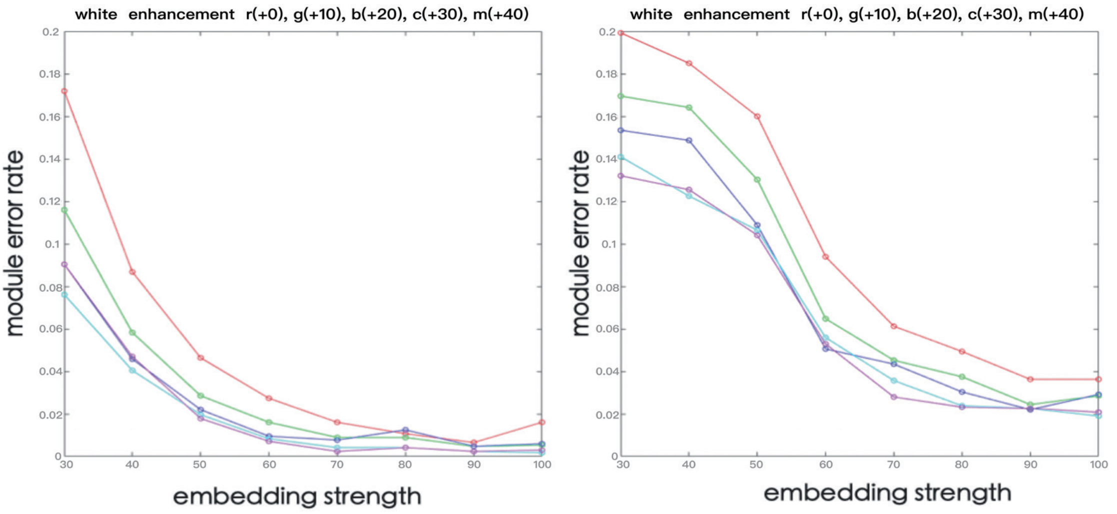


Fig. 9. Comparison of output methods showing error maps for information embedding strengths from 30 to 100: (a) high resolution and (b) low resolution.



(a) (b)

Fig. 10. (Color online) (a) High-resolution (digital printer) and (b) low-resolution (laser printer) module error rates for white dot enhancement for printed graphic QR codes.

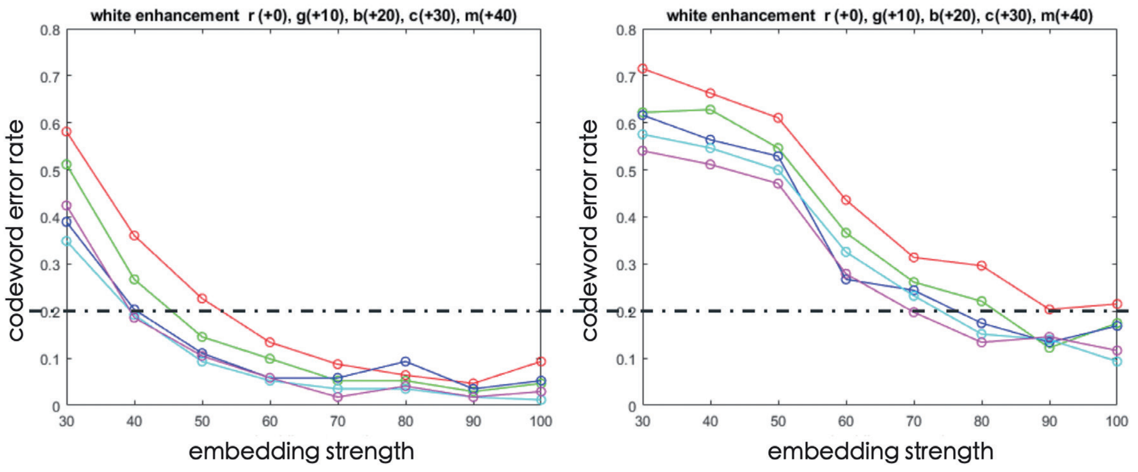
methods tend to produce more false black errors than false white errors. Regarding the (a) high-resolution and (b) low-resolution module error rates, enhancing white information dots suppresses the false-black recognition errors caused by dot gain. When the white dot information is enhanced, the module error rate is reduced and the high-resolution error rate is lowered considerably.

3.3 Codeword error rate of white dot enhancement

The analysis results show that the codeword error rate of the low-resolution output [Fig. 11(b)] is much higher than that of the high-resolution output [Fig. 11(a)]. However, the codeword error rates decrease with higher information embedding strength and white dot enhancement. The error correction rate of the H-level QR code is below 30%, which means that the aesthetic QR code can be decoded stably. In this study, to account for experimental uncertainties, we set the error tolerance rate to 20% to ensure successful decoding and to select the optimal parameters, as shown in Fig. 11.

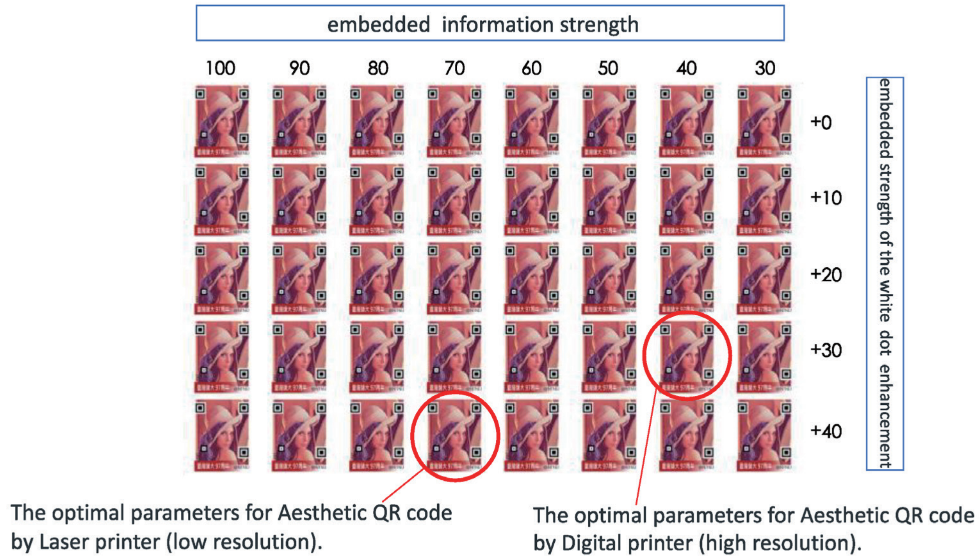
3.4 Optimal parameter selection for different output devices

By analyzing the codeword errors, we show that the output method (high resolution and low resolution) determines the optimal information embedding strength and white dot enhancement. For high-resolution output of the aesthetic QR code, the optimal information embedding strength is 40 and the optimal white dot enhancement is 30. For the low-resolution output, the optimal parameters are 70 and 40, respectively, as shown in Fig. 12.



(a) (b)

Fig. 11. (Color online) (a) High-resolution (digital printer) and (b) low-resolution (laser printer) codeword error rates for white dot enhancement for printed graphic QR code.



The optimal parameters for Aesthetic QR code by Laser printer (low resolution).

The optimal parameters for Aesthetic QR code by Digital printer (high resolution).

Fig. 12. (Color online) Optimal parameters for different output devices.

4. Conclusion

We show that different output devices have different effects on aesthetic QR code recognition. The proposed method is compatible with current printing processes. Small printed aesthetic QR codes look better and have higher recognition rates. For cover images given a specified output device, we determine the optimal QR code embedding method and recognition parameters. This work highlights the importance of output conditions for integrated applications of aesthetic QR codes. The proposed printed aesthetic QR codes are both aesthetically pleasing and maintain stable decoding ability.

Acknowledgments

This work was supported by the Ministry of Science and Technology, Taiwan, ROC, under grants MOST 108-2221-E-003-016 and MOST 109-2221-E-003-015.

References

1 Z. Yang, H. Xu, J. Deng, C. C. Loy, and W. C. Lac: IEEE Trans. Image Process. **27** (2018) 6093.
2 T. L. Yuan, Y. L. Wang, K. Xu, R. R. Martin, and S. M. Hu: IEEE Trans. Image Process. **28** (2019) 4413.
3 R. Kikuchi, S. Yoshikawa, P. K. Jayaraman, J. Zheng, and T. Maekawa: Comput.-Aided Des. **102** (2018) 215.
4 J. Zhang, D. Li, J. Jia, W. Sun, and G. Zhai: Proc. 2019 IEEE Visual Communications and Image Processing (IEEE, 2019) 1.
5 S. S. Lin, M. C. Hu, C. H. Lee, and T. Y. Lee: IEEE Trans. Multimedia **17** (2015) 1515.
6 G. J. Garateguy, G. R. Arce, D. L. Lau, and O. P. Villarreal: IEEE Trans. Image Process. **23** (2014) 2842.
7 Y. M. Wang, C. T. Sun, P. C. Kuan, C. S. Lu, and H. C. Wang: Proc. 2018 Int. Conf. Applied System Innovation (ICASI, 2018).
8 S. H. Hung, C. Y. Yao, Y. J. Fang, P. Tan, R. R. Lee, and H. K. Chu: IEEE Trans. Visual Comput. Graphics **26** (2020) 2834.
9 M. Kuribayashi and M. Morii: IEICE Trans. Inf. Syst. **100** (2017) 42.

About the Authors

Yi-Huei Ho received her B.S. degree from Chinese Culture University, Taiwan, in 2019. She is a graduate student in the Department of Graphic Arts & Communications at National Taiwan Normal University.
(ni012318@gmail.com)

Tzren-Ru Chou received his Ph.D. degree from National Tsing Hua University, Taiwan, in 1995. He is with the Department of Graphic Arts & Communications at National Taiwan Normal University, where he has been an associate professor and is currently the department chair.
(trchou@ntnu.edu.tw)

Chun-Shien Lu received his Ph.D. degree from National Chung-Kung University, Taiwan, in 1998. He is a research fellow at the Institute of Information Science, Academia Sinica, Taiwan. (lcs@iis.sinica.edu.tw)

Hsi-Chun Wang received his B.S. degree from National Taiwan University, Taiwan, in 1985 and his Ph.D. degree from the University of Southern California, United States, in 1995. Since August 2000, he has been with the Department of Graphic Arts & Communications at National Taiwan Normal University, where he has been an assistant professor, associate professor, and department chair, and is currently a professor. (hsiwang@ntnu.edu.tw)