Design of Quick Response (QR) Barcode for Resistance Against Electromagnetic (EM) Information Leakage

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Abstract – The threat of electromagnetic (EM) information leakage of the display image from an information device is caused by eavesdropping of unintended EM leakage emanation. A proposed design of the quick response (QR) barcode keeps the information and makes decoding on the eavesdropped image difficult. The design uses selected colors in consideration of the correlation between EM wave leakage and the display color.

1. Introduction

The threat of e (EM) eavesdropping from display screen image of information device has been reported [1, 2], and there is a possible threat of EM information leakage as an effect of weak EM radiation from portable information devices [3–6]. The quick response (QR) barcode is a two-dimensional image information, and its error correction capability reads an incomplete reconstructed image.

By selecting colors of the image, the amplitude of the EM emanation can be taken into consideration [7–9]. We should consider that luminance of color does not directly effect on EM radiation. A barcode reader senses luminance of the display color, and EM radiation is governed by a display signal waveform of the encoded transmission. This article proposes a QR barcode design method that considers this different relationship and makes EM information leakage difficult by selecting multiple colors of the QR barcode that take into account encoding of the display color in the transmission protocol.

2. Measures Against EM Information Leakage by Selecting Display Color

The discussion in this article focuses on a transmission protocol named *low-voltage differential signaling* (LVDS) that is widely used in portable information devices such as tablets. It is reported that EM emanation from LVDS transmission depends on display color, and the reason is considered as EM radiation is caused by edges of transmission waveforms [10, 11]. The magnitude of EM radiation largely depends on number of bit inversions of the color encoded in the LVDS transmission waveform. Note that luminance of the display color does not directly effect the magnitude of the EM emanation.

A normal QR barcode is composed of two colors, e.g., white and black, and the difference of the colors is essential in machine reading. Evaluation of the read performance in the QR barcode in this article uses the luminance value of human vision (ITU-R BT.601) [12] that is calculated by (1):

$$Y = 0.299R + 0.587G + 0.114B \tag{1}$$

The authors propose to arrange the display colors for the QR barcode by considering EM emanation or the number of bit inversions of the LVDS transmission. Table 1 shows the encoding of four colors used in the proposed design of the QR barcode. Two colors with high luminance (bright) values are RGB (0 192 0) and RGB (0 192 96), and the other colors with low luminance (dark) values are RGB (0 0 96) and RGB (96 0 96).

The ideal design of the colors is that there is little to no difference in the amplitude of EM emanation between the white and black parts to hide the differences of the white and black parts of the QR barcode in the reconstructed image. A pair of colors for white and black was selected to have the same number of bit inversions.

Table 1. Color encoding in the proposed design of the QR barcode

RGB value/luminance	LVDS data CH1/CH2/CH3	Bit inversion
Test image 1		
0 192 0/113 (white)	0000000 0011000 xxx0000	Rise 1, Fall 1
0 0 96/11 (black)	0000000 0000000 xxx0110	Rise 1, Fall 1
Test image 2		
0 192 96/124 (white)	0000000 0011000 xxx0110	Rise 2, Fall 2
96 0 96/40 (black)	0011000 0000000 xxx0110	Rise 2, Fall 2

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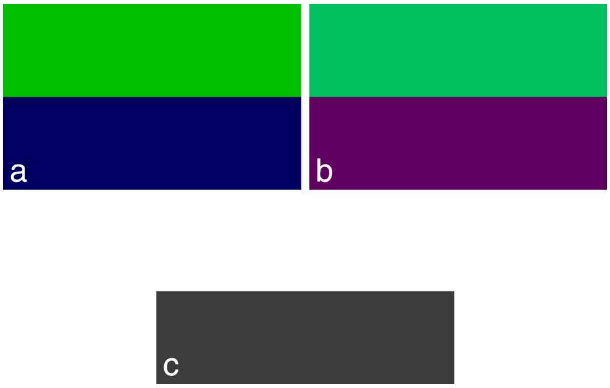

Figure 1. Test images for measurement of EM emanation.

Evaluation of the proposed design is confirmed by amplitude of the EM emanation by using the test images shown in Figure 1. The test image in Figure 1a is a combination of two colors for test image 1, and Figure 1b is made of a pair of colors for test image 2. Test image 3 is also designed in white (RGB 255 255 255) and black (RGB 60 60 60), shown in Figure 1c, as a comparative case. Table 2 shows the color encoding of these two colors for Figure 2c.

The EM emanation from a tablet device that used LVDS transmission was measured by using a spectrum analyzer and an EM probe. Configuration of the experiment is shown as Figure 2, and the measured result is in Figure 3. The difference in amplitude of the EM emanation from the selected display colors is small in both cases of the test image 1 (Figure 3a) and test image 2 (Figure 3b), while test image 3 (Figure 3c) shows a clear difference. Therefore, the proposed design of a QR barcode using the colors shown in

Table 2. Color encoding in the QR barcode for comparison

RGB value/luminance	LVDS data CH1/CH2/CH3	Bit inversion
Test image 3		
255 255 255/255 (white)	1111111	Rise 0, Fall 0
	1111111	
	xxx1111	
60 60 60/60 (black)	1001111	Rise 3, Fall 2
	1100111	
	xxx0011	

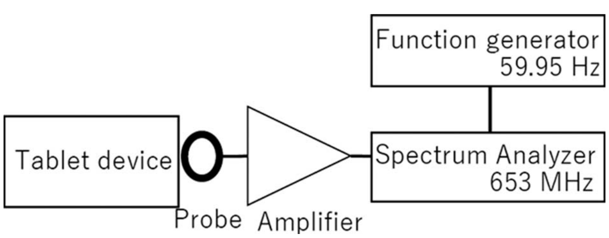

Figure 2. Experimental setup to measure EM emanation from LVDS transmission.

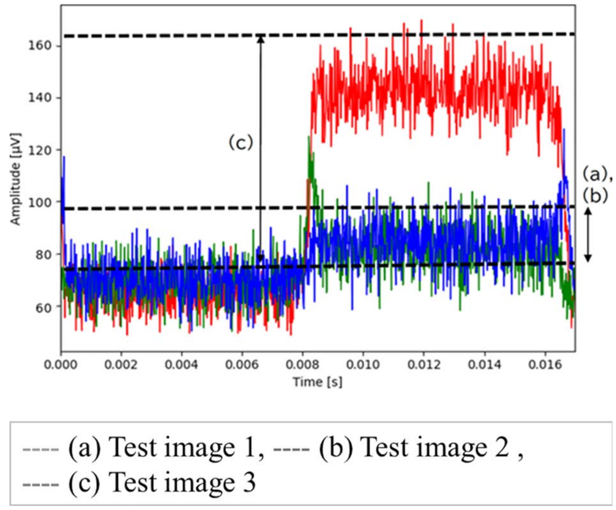

Figure 3. Amplitude of EM emanation in the test image.

Table 1 makes it difficult to read information on the reconstructed barcode.

The detected signal in this simplified configuration is small (75 μV to 160 μV). A similar experiment using the same tablet proved the image can be reconstructed at a distance 2 m [5]. The possibility to detect the image waveform may be improved by using a sensitive probe, a directive antenna, or digital signal processing, but the authors do not discuss these improvements in this article.

3. Design of QR barcode for Resistance Against EM Information Leakage

Figure 4 shows a sample QR barcode that is based on QR code version 1 (H) and arranged by using the

Figure 4. Sample QR barcode by the proposed method.

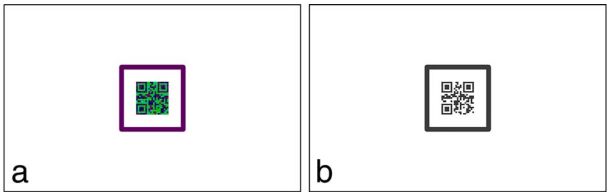

Figure 5. Test images of designed QR barcode.

four colors, shown in Table 1. Two colors are randomly arranged on each of the white and black parts of the QR barcode image. This code contains a text message *true* and is readable by a camera of a smartphone.

Figure 5 shows a set of test images of the designed QR barcode, and Figure 5a is a proposed barcode pasted on a white background (RGB 255 255 255) of 1920 × 1200. The QR barcode image shown in Figure 5b is a comparative case that uses two colors in Table 2. A frame line is added to each of them to indicate position of the QR barcode on the reconstructed image.

4. Experiment

4.1 Image Reconstruction From EM Emanation

Figure 6 shows the experimental setup. The EM emanation is observed while displaying the test images (shown in Figure 5) on the tablet device that uses the LVDS transmission protocol. The EM emanation at frequency 653 MHz was measured at a sampling rate of 25 MHz.

Figure 7 shows the reconstructed images derived from EM emanation for the test images of Figure 5. Figure 8 shows images cut out by extracting the frame line on the reconstructed image. The cropped images

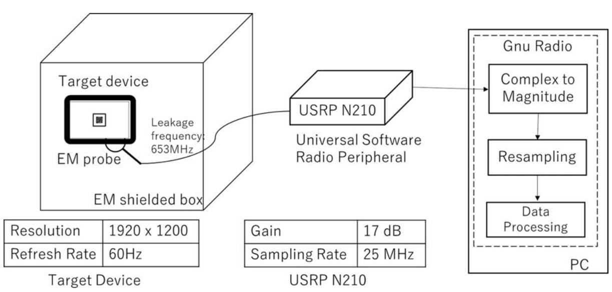

Figure 6. Experimental setup.

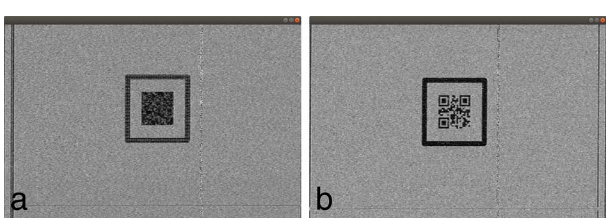

Figure 7. Reconstructed image from EM emanation.

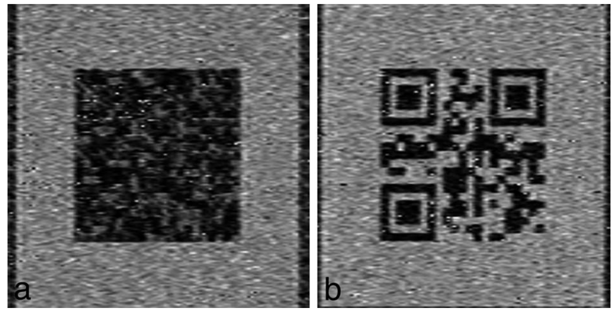

Figure 8. Image cropped at the border.

were read with a smartphone camera by using a standard camera application on an iOS 12 Smartphone.

The information could not be obtained from Figure 8a, but the text information, true, could be obtained in Figure 8b. Therefore, the information stored in the QR barcode image can be leaked, if any countermeasure against EM emanation is not considered, and the proposed design is effective as a countermeasure against EM information leakage from the reconstructed image.

4.2 Shape Restoration by Image Binarization

The next experiment is to observe whether the shape of the QR barcode could be restored by discriminating two colors of the reconstructed QR barcode image. The image of the QR barcode was extracted from the reconstructed image in Figure 8, and then each pixel in the image was converted to grayscale value Y from 0 to 255 by applying (2).

$$Y = (R + G + B)/3 \tag{2}$$

As a fundamental study on statistical analysis, Figure 9 shows histogram of the images in Figure 8. The result from the proposed method, shown as Figure 9a, has only one peak, and Y values for black and white pixels are confused. For no countermeasure in Figure 9b, we can observe two peaks for two colors.

Each pixel value Y is binarized; if value Y of a pixel is smaller than threshold value t, the pixel is classified into black. A pixel with $Y > t$ is classified into white. The binarized image was pasted on a white background of 1920 × 1200, and readability was tested by using cv2.QRCodeDetector () of the OpenCV4 library for image processing.

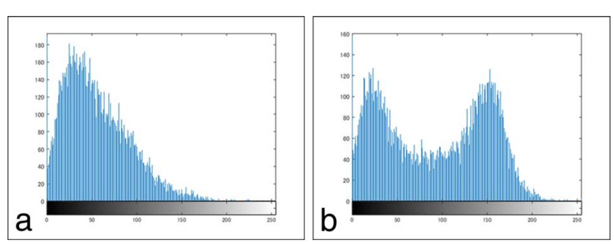

Figure 9. Histogram of images.

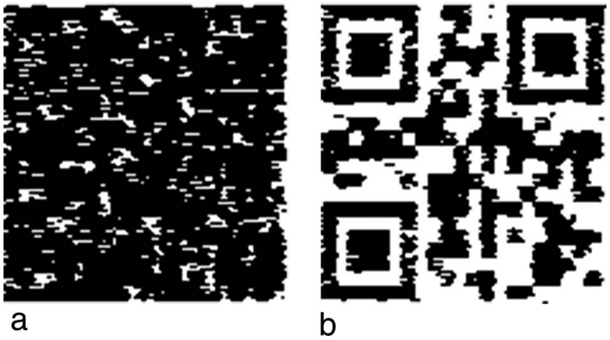

Figure 10. Binarized images at $t = 96$.

Figure 10 shows samples of the processed QR barcode images at $t = 96$. The QR barcode image (Figure 10a) for the proposed countermeasure could not obtain the stored information. The image (Figure 10b) that did not take the countermeasure against EM emanation was able to obtain the stored text information, true, for threshold values $t = 96$, 97, or 98. Therefore, it was shown that it is difficult to obtain the information in a QR barcode by taking a countermeasure against EM emanation by the proposed method. Signal processing for remote reconstruction of the screen image from EM leakage [5] can be applied to improve successful reconstruction.

5. Conclusion

This article discussed a design of a multicolor QR barcode that made EM information leakage difficult with the encoding of the LVDS transmission signal. The proposed design used the selected four colors to control different luminance (black or white) and EM emanation. Experiments on the reconstruction of the image from EM emanation showed that it is difficult to obtain the information of QR barcode in the proposed design. The proposed design takes a countermeasure against EM emanation and is resistant against EM information leakage.

6. References

1. W. van Eck, “Electromagnetic Radiation From Video Display Units: An Eavesdropping Risk?” *Computers and Security*, **4**, 4, December 1985, pp. 269-286.
2. H. Sekiguchi and S. Seto: “Estimation of Receivable Distance for Radiated Disturbance Containing Information Signal From Information Technology Equipment,” IEEE International Symposium on Electromagnetic Compatibility, Long Beach, CA, USA, August 14–19, 2011, pp. 942-945.
3. M. Jian, L. Jinminga, Z. Jiemina, H, Zhenzhongb, and S. Senc, “A Method for Detecting Image Information Leakage Risk from Electromagnetic Emission of Computer Monitors,” *Journal of Intelligent & Fuzzy Systems*, **40**, 2, February 2021, pp. 2981-2991.
4. H. Tanaka, “Information Leakage via Electromagnetic Emanations and Evaluation of Tempest Countermeasures,” International Conference on Information Systems Security ICISS 2007, pp 167-179.
5. Y. Hayashi, N. Homma, M. Miura, T. Aoki, and H. Sone, “A Threat for Tablet PCs in Public Space: Remote Visualization of Screen Images Using EM Emanation,” 2014 ACM SIGSAC Conference on Computer and Communications Security, Scottsdale, AZ, USA November 3–7, 2014, pp. 954-965.
6. S. Wang, Y. Qiu, J. Tian, and Q. Xu, “Countermeasure for Electromagnetic Information Leakage of Digital Video Cable,” 2016 Asia-Pacific International Symposium on Electromagnetic Compatibility, Shenzhen, China, May 17–21, 2016, pp. 44-46.
7. T. Watanabe, H. Nagayoshi, T. Urano, T. Uemura, and H. Sako, “Countermeasure for Electromagnetic Screen Image Leakage Based on Color Mixing in Human Brain,” 2010 IEEE International Symposium on Electromagnetic Compatibility, Fort Lauderdale, FL, July 25–30, 2010, pp. 138-142.
8. N. Teraura and K. Sakurai, “Information Hiding of Two-Dimensional Code by Multi-Layer Optical,” 2012 10th IEEE International Symposium on Parallel and Distributed Processing With Applications, Leganes, Spain, July 10–13, 2012, pp. 770-777.
9. R. Birukawa, Y. Hayashi, T. Mizuki, and H. Sone, “A Study on an Effective Evaluation Method for EM Information Leakage Without Reconstructing Screen,” 2019 International Symposium on Electromagnetic Compatibility, Barcelona, Spain, September 2–6, 2019, pp. 383-387.
10. H.-W. Shim and T. H. Hubing, “Model for Estimating Radiated Emissions From a Printed Circuit Board With Attached Cables due to Voltage-Driven Sources,” *IEEE Transactions on Electromagnetic Compatibility*, **47**, 4, November 2005, pp. 899-907.
11. M. G. Kuhn, *Compromising Emanations: Eavesdropping Risks of Computer Displays*, Technical Report UCAM-CL-TR-577, Cambridge, UK, University of Cambridge, December 2003.
12. International Telecommunications Union, “BT.601 : Studio Encoding Parameters of Digital Television for Standard 4:3 and Wide-Screen 16:9 Aspect Ratios, ITU-R BT.601-7,” https://www.itu.int/dms_pubrec/itu-r/rec/bt/R-REC-BT.601-7-201103-I!!PDF-E.pdf (Accessed day November 2020).