Journal of Information Hiding and Multimedia Signal Processing ©2019 ISSN 2073-4212
Ubiquitous International Volume **10**, Number **2**, March **2019**

Print-Scan Resistant Two-Level QR Code

Hui-Li Cai and Bin Yan*

College of Electronic, Communication and Physics
Shandong University of Science and Technology
579, Qian-Wan-Gang Road, Qingdao, P. R. China, 266590
yanbinhit@hotmail.com

Jeng-Shyang Pan

College of Computer Science and Engineering
Shandong University of Science and Technology
579, Qian-Wan-Gang Road, Qingdao, P. R. China, 266590
jspan@cc.kuas.edu.tw

Jiong-Liang Ye

College of Electronic, Communication and Physics
Shandong University of Science and Technology
579, Qian-Wan-Gang Road, Qingdao, P. R. China, 266590

*Corresponding author: Bin Yan

Received July 2018; revised November 2018

Abstract. *Aiming at increasing the capacity of Quick Response (QR) codes that are resistant to print-and-scan(P&S) process, this paper proposes a two-level QR code that replaces the black and white modules in the standard QR code with specially designed modules. First, at the encoder side, during the generation of two-level QR code, error correction code (ECC) and stream encryption are used for the second-level message to ensure security. Then, taking the second-level message into consideration, the black and white modules in the standard QR code are replaced with the specific modules designed. At the decoder side, the first-level message can be decoded and recognized by the standard QR code scanner. The second-level message can be extracted with the help of demodulator and secret key. Finally, considering the impact of the P&S process on two-level QR code images, four low-pass textured patterns are designed for white and black modules. Experimental results demonstrate that the proposed algorithm is superior to the reference method in terms of high storage capacity and resistance to P&S process.*

Keywords: QR code capacity, Two-level QR code, Stream encryption, Module modulation, Print-and-scan process

1. **Introduction.** In recent years, with the rapid development of the Internet and the popularity of portable smart mobile terminals such as mobile phones, the QR Code has rapidly become one of the main methods for information exchange [1]. QR code is a two-dimensional (2D) barcode developed by Denso Wave Corporation in 1994. It contains data in both vertical and horizontal directions. Therefore, it can carry a large amount of information. It can deliver a variety of content such as text, web links, numbers and multimedia data. There are forty different versions of the QR code. Each version has its own data storage capacity. Version 40 can store up to 7089 digits or 4296 alphanumeric characters or 1817 Chinese characters.

Although the data density of the QR code is high, the amount of information in the 2D barcode is still limited. In 2012, Victor proposed to use data pre-compression to increase QR code capacity [2]. In the research of direct expansion, Niu *et. al.* proposed a color QR code in 2015 [3]. Li *et. al.* proposed a color QR code that adapted to the logo shape in 2016 [4]. These algorithms improved the capacities of the standard QR code. But, the error decoding rate is relatively high.

Security risk is another critical issue in QR code applications, such as payment by scanning QR code. Improving the security level has become one of the research focuses. Yang discussed the various attacks on QR codes in different application scenarios [5]. Standard QR codes can be read and recognized by anyone. In some applications, the information in the QR code needs to be closely controlled. Limited parts of the secret information should only be visible to authorized users. In this case, the standard QR code obviously cannot meet the demand. At present, there are many studies on using encryption and information hiding technology for QR codes. But these methods encrypt all information and decrypt it when scanning. This prevents information from being leaked or tampered with. However, not all messages carried by the QR code are important and should be kept confidential to everyone. Multilevel confidentiality control is needed in some applications. Therefore, considering these capacity and security challenges, the research problem of this paper is: how to design a reliable QR code that can increase the capacity and provide multilevel security control?

To improve the capacity and security of the QR code, Tkachenko *et. al.* proposed a new QR code scheme [6], a two-level QR (2LQR) code. The 2LQR code not only has a high capacity, but also can be used for document verification. This code has two levels of storage: public storage and private storage. The public storage part follows the QR code standard. Therefore, it can be read by any standard QR code scanner. The private storage level is built by replacing the black modules with specific textured patterns. This not only increases the storage capacity of the QR code, but also distinguishes the original document from a scanned copy. In order to authenticate the document, 2LQR code uses high-pass textured patterns that are sensitive to the P&S process. The algorithm in [6] has two problems:

- The 2LQR code image is not resistant to P&S process. To increase capacity, the second-level message should have similar robustness as the first-level message.
- Only black modules are replaced by textured patterns. This limits the capacity of the second-level message.

In application scenarios where the embedded information in QR code to be widely disseminated, the QR code image needs to be resistant to P&S process. In this paper, we improve the algorithm in [6] and design new textured patterns and module modulation scheme. The smallest textured pattern we designed requires only 3×3 pixels, which greatly reduces the physical size of the QR code and satisfies the practical situation when the printing area is limited. Tkachenko *et. al.* only replaced the black modules in the QR code. In our design, we have replaced both the black and white modules to generate a new improved two-level QR code. This further expands the capacity of the QR code. P&S process can be modelled as low-pass filtering. So, the texture pattern for second-level message needs to put most of its energy in low frequency band. Therefore, we design four low-pass patterns for second-level message. These four low-pass patterns have higher robustness to the P&S process. After two P&S processes, the four low-pass modules still can be distinguished.

The contributions of this paper can be summarized as follows:

- The designed four low-pass textured patterns have higher robustness to the P&S process.
- By replacing both the black and white modules, we greatly increase the capacity of the QR code compared with [6].

2. **Related work.** In this section, we briefly review the research of the QR code capacity expansion and discuss the impact of the P&S process on QR code images. This is the basis for designing the modules of a two-level QR code.

2.1. **Capacity expansion of 2D barcode.** For the 2LQR code proposed by Tkachenko *et. al.* [6], the textured patterns are high-pass, in order to be sensitive to P&S process, as shown in Fig. 1. In addition, a single module occupies a large number of pixels. This makes the textured patterns to be blurred when the size of 2LQR code is too small. Meanwhile, it severely interferes with the recognition of second-level message. The second-level storage capacity in [6] is significantly lower than the first-level storage capacity.

FIGURE 1. The textured patterns for the replaced modules in [6].

For the same physical size, a color QR code has a higher capacity than the black and white one. Yang *et. al.* proposed a color QR code scheme [7], the *high-capacity QR code* (HiQ). HiQ constructs a color QR code by combining multiple monochrome QR codes in a layered manner. Therefore, the structure of the conventional QR code and the strength of its design are preserved. The color QR code optimized the decoding algorithm for high-density QR codes. Therefore, robustness and fast decoding are achieved on mobile devices. For decoding, a learning-based algorithm was used for color restoration. This algorithm increases the capacity of the QR code. However, the color QR code has certain limitations. First, it cannot be read by a standard QR code scanner. Second, it needs to be printed by a color printer. These shortcomings limit the development and application of color QR codes.

Lin *et. al.* proposed a method for securely embedding secret information into a QR code [8]. The contents of the QR code can be read directly using the standard QR code scanner. This method is based on the error correction capability of the QR code. More information is hidden with little change to the QR code image. Using this method to hide information, unauthorized users can only decode the contents of the QR code. Only authorized users can extract the hidden message.

Grillo *et. al.* proposed a new encoding and decoding algorithm of 2D code [9], *high capacity colored two dimensional (HCC2D) code*. It uses color to increase the data density of the QR code. HCC2D can store more data than QR codes while maintaining the strong reliability and robustness of QR codes. The color modules in HCC2D has the problem of color distortion during the P&S process.

In Table 1, we compare the characteristics of the color QR code generated by [9] with the 2LQR code generated by [6]. Neither the color QR code nor the 2LQR code can meet our requirement of robust capacity expansion. This motivates our improved 2LQR code with improved capacity and robustness to P&S process.

Table 1. Comparison of color QR code with 2LQR code

Barcode	*Private-level storage*	*Use color printer*	*Resist P&S process*
Color QR code	No	Yes	No
2LQR code	Yes	No	No

2.2. **Influence of P&S process.** The QR code system is mainly divided into two parts: generation of QR code, and the recognition of QR code. In many application scenarios, such as payment by scanning a printed QR code, the QR code image undergoes two processes: digital-to-analog (D/A) conversion and analog-to-digital (A/D) conversion. This is usually referred to as the P&S process.

At present, digital images are mostly printed by laser printers. For grayscale image, laser printers use halftone technology to print it. The most commonly used halftone techniques at present are ordered dithering and error diffusion, which use a set of binary dots to approximate the gray levels. In general, the output image after halftoning is roughly the same as the original image. However, there are some distortions in the local details due to the fact that the dots printed by printers are not ideal. It can be seen that the halftoning process of the laser printer in printing an image has a large influence on the input image. This causes a certain degree of distortion in the QR code image.

The scanner is a digital image signal input device. The quality of the scanned image depends on the performance of scanner's internal sensor. Because human's visual system and electronic components react differently to light, there are also differences in the visual perception of the image. The instability of the electronic circuit, when it is working, can make a lot of noise.

The effects of the P&S process on the image include pixel value distortion and geometric distortion. Lin *et. al.* pointed out that pixel value distortion is caused by illumination intensity, contrast, gamma correction, hue change, and blurring between adjacent pixels [10]. Geometric distortion is caused by the image rotation, scaling and clipping. They proposed a print-and-scan model based on pixel value distortion and geometric distortion. Tkachenko *et. al.* found that after the P&S process, the pixel values around the module will change [11]. When the version of the QR code increases, the interference between the modules increases accordingly. This will obviously affect the reading speed and recognition rate of the QR code.

3. **The proposed algorithm.** The block diagram of the proposed two-level QR code is shown in Fig. 2. It consists of three steps: design of modules, generation of the first-level QR code and generation of the second-level QR code.

The first-level QR code can store public message and can be read and recognized by a standard QR code scanner. The second-level QR code can store private message and can only be read by some authorized users. Considering the influence of the P&S process on the second-level message, error correction bits are added to the second-level message. In order to increase confidentiality, the second-level message is encrypted using a stream cipher.

3.1. **The design of modules.** In order to increase the data capacity of the QR code, we have embedded the second-level message M_2 into both the black modules and the white modules. Without affecting the reading and recognition of the QR code, four low-pass patterns representing "0" and "1" in black modules and white modules are designed. According to the embedded bits, we use the following modulation scheme of modules:

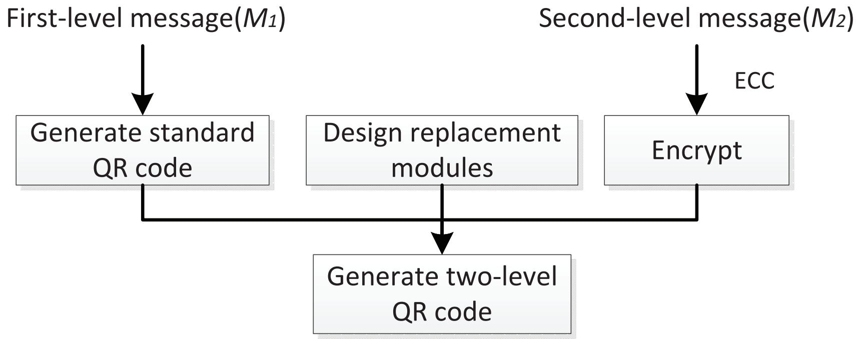


FIGURE 2. Block diagram of two-level QR code.

$$M_B = \begin{cases} M_{B1}, & \text{if} \quad C_2 = \text{“1”}; \\ M_{B2}, & \text{if} \quad C_2 = \text{“0”}. \end{cases}$$

$$M_W = \begin{cases} M_{W1}, & \text{if} \quad C_2 = \text{“1”}; \\ M_{W2}, & \text{if} \quad C_2 = \text{“0”}. \end{cases}$$

where M_B is the black module, M_W is the white module, M_{B1} is the first textured pattern, M_{B2} is the second textured pattern, M_{W1} is third the textured pattern, M_{W2} is the fourth textured pattern, and C_2 is the second-level message after the error correction encoding and stream cipher encryption.

We designed two set of textured patterns, $\mathcal{M}_1$ and $\mathcal{M}_2$. The sizes of the designed modules are 3×3, 4×4, 5×5, 6×6 respectively. The modules from the first set $\mathcal{M}_1$ are shown in Fig. 3. The main feature for $\mathcal{M}_1$ is the square shape interior and exterior regions on each module.

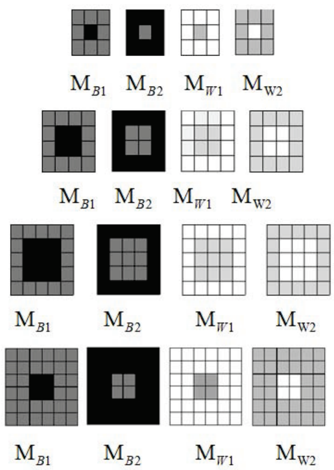


FIGURE 3. The modules with various sizes for the first set of textured patterns $\mathcal{M}_1$.

From our experiment with the P&S process, we find that 2LQR Code in [6] has the following two problems after P&S:

1. The interference between the modules becomes larger.
2. The textured modules are distorted. When the size of the QR code is small, some textured modules cannot be recognized.

The P&S process may introduce inter-module interference and intra-module interference. For inter-module interference, different modules interfere with each other. For intra-module interference, the internal pixels and external pixels in the same module may interfere with each other. These interferences affect the correct decoding rate of the second-level message.

To reduce the interferences from P&S process, a second set of textured patterns $\mathcal{M}_2$ are also designed, as shown in Fig. 4. The interior region is square-shaped and the exterior region is rhombus-shaped. This may help to reduce the inter-module interference.

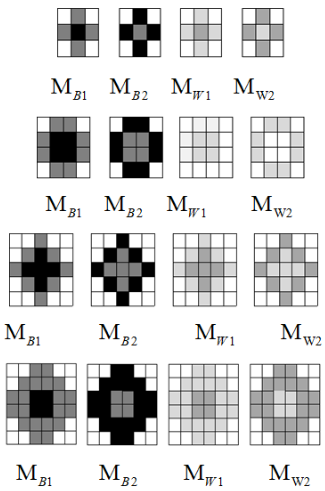


FIGURE 4. The modules with various sizes for the second set of textured patterns $\mathcal{M}_2$.

To help the decoder to distinguish between the four textured patterns, the contrast between the interior and the exterior region must be large enough. Specifically, in black modules and white modules, the differences between the internal pixel values and the external pixel values need to be large enough to ensure that the second-level message can still be recognized after P&S process. Similarly, the differences between the average pixel value of the black modules and the average pixel value of the white modules also need to be large enough to ensure that the first-level message can be recognized after P&S process. Considering the above compromise, the internal and external pixel values in the black module we set are 0 and 70 respectively, and the internal and external pixel values in the white module we set are 255 and 130 respectively. Through experiments, we find that these values can guarantee that the decoding speed of the two-level QR code is the fastest. The generated QR codes are shown in Fig. 5.

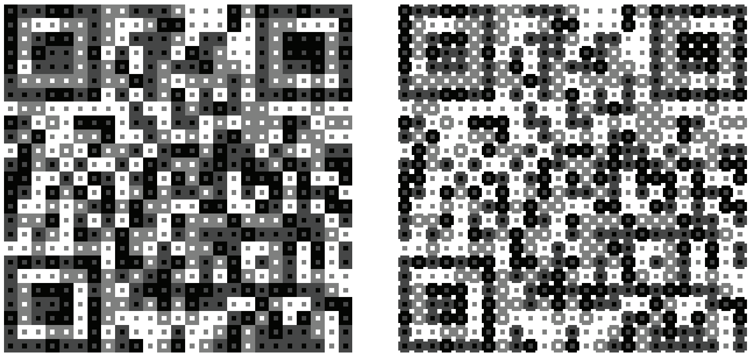
3.2. **Generation of first-level QR code.** For the first-level QR code, we use the standard QR code generation process to generate it. The generation process is outlined as follows:

Step 1: Data analysis. The input first-level message M_1 is analyzed and the type of characters to be encoded is determined.

Step 2: According to the selected data mode and the data conversion method corresponding to the mode, the data character is converted into a bit stream.

Step 3: Error correction coding. Codewords are blocked in sequence. The corresponding error correction codewords of blocks are generated. Error correction codewords are added into the corresponding data codewords sequence.

Step 4: Structure the final information. Data codewords and error correction codewords are placed in each block. Padding codewords are added if necessary.



(a) (b)

FIGURE 5. Two-Level QR code generated using the proposed low-pass textured patterns. (a) Result using the first set of textured patterns $\mathcal{M}_1$, (b) Result using the second set of textured patterns $\mathcal{M}_2$.

Step 5: Arrange modules in the matrix. Position tags, timing patterns, alignment patterns and codeword modules are put together into a data matrix.

Step 6: Masking. The masking images are applied to the coding region.

Step 7: Generate format and version information to form a QR code image.

3.3. **Generation of second-level QR code.** For the second-level message M_2, a second datastream B_2 is generated using Reed-Solomon error correction coding to ensure that the two-level QR code can be correctly recognized after P&S process.

First, M_2 is converted into a binary bitstream sequence. A codeword is formed by every 8 bits. The bitstream sequence is converted into a codeword sequence.

Then, the data codewords are divided into corresponding data blocks. The corresponding error correction codewords of each block are calculated. The calculation steps are as follows.

Step 1: Establish data codewords polynomials.

$$c(x) = c_{n-1}x^{n-1} + c_{n-2}x^{n-2} + \cdots + c_1x + c_0$$

Step 2: In the polynomial that generates the error correction codewords, the coefficients of the polynomial are composed of the data codewords of the corresponding data block. The coefficient of the highest order term is the first codeword. The lowest order coefficient is the last codeword in the data block. The polynomials that generate k error correction codewords are:

$$g(x) = (x - 2^0)(x - 2^1) \cdots (x - 2^{k-1})$$

where, k is the number of error correction codewords corresponding to each data block.

Step 3: Calculate error correction codewords. The value of the error correction codewords in each data block are the coefficient of the remaining polynomial. They are obtained by dividing the data codewords polynomial $c(x)$ by the error correction codewords polynomial $g(x)$. Among them, the coefficient of the highest order term of the remaining polynomial is the value of the first error correction codeword. The coefficient of the lowest order term is the value of the last error correction codeword.

Next, the data stream B_2 generated by the error correction code is encrypted using the stream cipher. The same key is used for encryption and decryption of stream ciphers. Each time the data stream B_2 is encrypted with the key, ciphertext data streams are obtained. Let E_k be the encryption function and D_k be the decryption function, then the encryption process of the stream cipher is as follows:

$$c_i = E_{k_i}(b_i), \qquad i = 1, 2, \cdots, n.$$

where the data stream is $B_2 = b_1, b_2, \cdots b_n$, the key stream is $K = k_1, k_2, \cdots k_n$. This is done by using stream cipher:

$$c_i = b_i \oplus k_i.$$

The corresponding decryption process is as follows:

$$b_i = D_{k_i}(c_i), \qquad i = 1, 2, \cdots, n.$$

By doing so, an encrypted data stream, that is, encrypted second-level message is generated.

Taking into account the encrypted second-level message M_2, we replace the black and white modules of the QR code with the textured patterns. Finally, a two-level QR code is generated.

4. **The decoding of two-level QR code.** The decoding of the two-level QR code includes the decoding of the first-level QR code and the decoding of the second-level QR code. The first-level message of the two-level QR code can be recognized by the standard QR code scanner. The second-level message is accessible only by authorized users having the encryption key K.

4.1. **The decoding of first-level QR code.** The first-level message M_1 is public message and can be obtained by everyone. The decoding process of the first-level message is as follows:

Step 1: Locate and get the symbol image. Dark and light colored modules are identified as "1" and "0".

Step 2: Read the format information.

Step 3: Read the version information and determine the version of the symbol.

Step 4: XOR the bitmap of the coding area with a mask pattern to eliminate the mask. The mask pattern has been derived from the format information.

Step 5: According to the rules of module arrangement, characters are read and data codewords and error correction codewords are recovered.

Step 6: Detect the error with the error correction codewords corresponding to the error correction level. If an error is found, the error is corrected immediately.

Step 7: Divide data codewords into multiple parts based on the mode indicator and the character count indicator.

Step 8: Finally, the data characters are decoded according to the mode used and the result is output.

4.2. **The decoding of second-level QR code.** After decoding the first-level QR code, now we know the version and the number of modules of the QR code. Then, the QR code is divided into modules and each module is processed to obtain the second-level message $\hat{M}_2$. The second-level message is decoded according to whether the difference between the average internal pixel values and the average external pixel values is greater than "0" or not. The schematic diagram of internal and external of the modules is shown in Fig. 6.

For the textured patterns in the second-level QR code, when the average of internal pixel values is greater than the average of external pixel values, it is decoded as "1". Otherwise, it is decoded as "0". That is:

$$\hat{B}(m, n) = \text{sgn}[\bar{M}_I^{(m,n)} - \bar{M}_O^{(m,n)}].$$

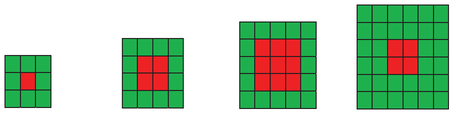


FIGURE 6. Schematic diagram of internal and external of the modules.(The colors are used to highlight the differences. They are actually in grayscale.)

where (m, n) is the position of the module. $\mathrm{sgn}(x)$ is the signum function that returns 1 for non-negative numbers x and 0 for negative numbers x. $\bar{M}_I^{(m,n)}$ and $\bar{M}_O^{(m,n)}$ are mean values of the internal and external regions, respectively.

$$\bar{M}_I^{(m,n)} = \frac{1}{|\mathcal{I}|} \sum_{(i,j)\in\mathcal{I}} I_{ij}.$$

$$\bar{M}_O^{(m,n)} = \frac{1}{|\mathcal{O}|} \sum_{(i,j)\in\mathcal{O}} I_{ij}.$$

where, $\mathcal{I}$ is the set of internal pixels of module (m, n), $\mathcal{O}$ is the set of external pixels of module (m, n), $|\mathcal{I}|$ is the number of internal pixels in module (m, n), $|\mathcal{O}|$ is the number of external pixels in module (m, n), (i, j) is the position of the pixel, I_{ij} is the pixel value at the position (i, j).

5. **Experiments.** The purpose of this paper is to increase the capacity and security of the QR code. In the experiment, the encoding and decoding of two-level QR code are implemented in environment of MATLAB R2014a. Three performances are analyzed, including the robustness of the second-level QR code to P&S process, storage capacity of the two-level QR code and the decoding time of the first-level QR code.

5.1. **Storage capacity analysis.** In each version of the QR code, the capacity is the largest when the error correction level is L. So, In the experiments for storage capacity, the error correction level of the QR code is chosen as L. The version of the QR code varies from 1 to 7, which is common in practical applications. We compare three algorithms: the proposed algorithm, the algorithm in [6], and the standard QR code. The result is shown in Fig. 7.

It can be seen from Fig. 7 that, compared to [6], the proposed algorithm has a greater advantage in capacity over the standard QR code. In Table 2, we calculate the relative increment in capacity for the proposed algorithm relative to [6]. We find that the lower the QR code version, the higher the storage capacity improvement. When the version of the QR code is above 5, the relative increment is stable around 35%.

TABLE 2. Relative increase of capacity of proposed algorithm compared with [6]

Version	1	2	3	4	5	6	7
Expansion rate	86%	61%	47%	40%	36%	35%	35%

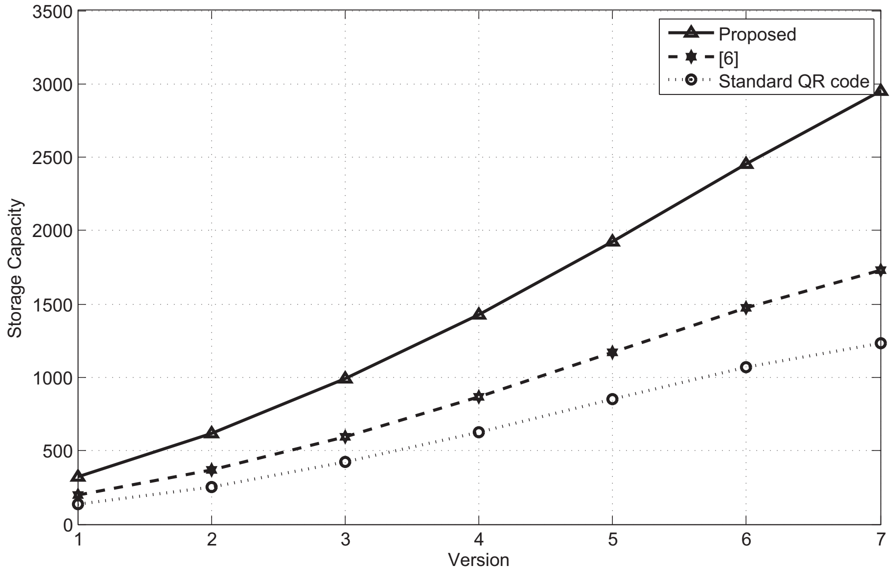


FIGURE 7. Comparison of the total storage capacity between proposed algorithm, [6] and standard QR code.

5.2. **Performance in resistance to P&S process.** In the experiment of resistance to P&S process, the printer we used is HP LaserJet P1007 with a resolution of 600 dpi. The scanner we used is the Epson Perfection V370 Photo with a resolution of 600 dpi. The two-level QR code, which uses the first set of textured patterns $\mathcal{M}_1$, is called 2LQR Code1. The two-level QR code, which uses the second set of textured patterns $\mathcal{M}_2$, is called 2LQR Code2. In order to compare the changes of the image that after the P&S process, we apply P&S processes twice to 2LQR Code1, 2LQR Code2 and [6]. The original QR image and the QR image after once and twice P&S are shown in Table 3.

Then, we compare the first-level correct recognition rate and the second-level error decoding rate of the two-level QR code. The results are shown in Table 4 and Table 5.

From Table 4 and Table 5, we find that the two-level QR code generated by the second set of textured patterns $\mathcal{M}_2$ does not affect the correct recognition rate of the first-level message. The error decoding rate of the second-level message is only 0.96% after twice P&S processes. In other words, the proposed algorithm has better performance in resistance to P&S process.

5.3. **Decoding time of the first-level QR code.** The replacement of modules with textured patterns may interfere with the decoding of the first-level message. The reason is that the decoding algorithm for first-level message is designed based on the assumption of uniform black or white modules. So we have to test the decoding time for the first-level message.

In the experiment, we use different configurations for the internal and external pixel values in the black module and the white module. Then, we test the decoding time of the first-level QR code. The result is shown in Table 6. When the internal and external pixel values in the black module are 0 and 70 respectively, and the internal and external pixel values in the white module are 255 and 130 respectively, the decoding speed of the two-level QR code is the fastest.

In the experiment, we compare the decoding time of standard QR code, [6] and proposed algorithm. The results are shown in Table 7.

Table 3. Influence of P&S process on [6] and proposed algorithm

Barcode	No P&S	First P&S	Second P&S
[6]			
2LQR Code1			
2LQR Code2			

Table 4. Comparison of first-level correct recognition rate of [6] and proposed algorithm

Barcodes	No P&S	First P&S	Second P&S
[6]	100%	100%	100%
2LQR Code1	100%	100%	100%
2LQR Code2	100%	100%	100%

Table 5. Comparison of second-level error decoding rate of [6] and proposed algorithm

Barcodes	No P&S	First P&S	Second P&S
[6]	0%	0.073%	85.79%
2LQR Code1	0%	0%	5.6%
2LQR Code2	0%	0%	0.96%

From Table 7, we find that the decoding time of proposed algorithm is comparable with [6]. When scanning the proposed two-level QR code, it won't take a long time to wait to get the content of the QR code. For users, the time difference is not noticeable.

Table 6. Decoding time of the first-level QR code

Black Module		White Module		Decoding Time
internal pixel	external pixel	internal pixel	external pixel	
0	50	255	130	133ms
0	70	255	100	134ms
0	60	255	130	136ms
0	70	255	110	137ms
0	70	255	130	**126ms**
0	70	255	120	132ms
0	80	255	130	136ms
0	70	255	140	134ms

Table 7. Comparison of decoding time of standard QR code, [6] and proposed algorithm

Barcode	No P&S	First P&S	Second P&S
Standard QR code	100ms	101ms	103ms
[6]	121ms	124ms	125ms
2LQR Code1	134ms	141ms	159ms
2LQR Code2	126ms	122ms	121ms

6. **Conclusions.** In order to improve the capacity of QR code and performance in resistance to P&S process, a new improved two-level QR code is proposed, which replaces the black and white modules in the standard QR code with carefully designed low-pass textured patterns. If the version of the QR code is higher than 4, the relative improvement in storage capacity over standard QR code is stable around 35% compared to [6]. After twice P&S processes, the correct recognition rate of the first-level message is 100%, and the second-level error decoding rate of the proposed algorithm is only 0.96%. The decoding time of the new improved two-level QR code is comparable with [6]. Compared with [6], the proposed algorithm has greater advantages in storage capacity and resistance to P&S process.

Acknowledgement. This work is supported by Shandong Provincial Natural Science Foundation (No. ZR2014JL044) and the National Natural Science Foundation of China (NSFC)(No. 61272432).

REFERENCES

[1] A. N. C. of China, Basic Barcode Technology, Wuhan University Press, 2008.

[2] N. Victor, Enhancing the data capacity of QR codes by compressing the data before generationg, International Journal of Computer Applications 60 (2) (2012) 17–21.

[3] W.-H. Niu, H.-Q. Yan, Y.-B. Ge, A colored QR code design principle and encoding-decoding implementation, Transactions of Beijing Institute of Technology 35 (10) (2015) 1067–1073.

[4] D. Li, L.-J. Feng, H. Su, Design of a logo-shaped colored QR code, Electronics World 17 (112) (2016) 167–170.

[5] S. Yang, Two-dimensional code application and security analysis, Information Security and Technology 6 (8) (2015) 64–65.

[6] I. Tkachenko, W. Puech, C. Destruel, O. Strauss, J.-M. Gaudin, C. Guichard, Two-level QR code for private message sharing and document authentication, IEEE Transactions on information Forensics and Security 11 (3) (2016) 571–583.

[7] Z.-B. Yang, Z.-Y. Cheng, C.-L. Chen, W.-C. Lau, C.-M. Li, G.-C. Li, Towards robust color recovery for high capacity color QR codes, in: IEEE International Conference on Image Processing (ICIP2016), 2016, pp. 2866–2870.

[8] P.-Y. Lin, Y.-H. Chen, E. J.-L. Lu, P.-J. Chen, Secret hiding mechanism using QR barcode, in: International Conference on Signal-Image Technology and Internet-Based Systems, 2013, pp. 22–25.

[9] A. Grillo, A. Lentini, M. Querini, G. F.Italiano, High capacity colored two dimensional codes, in: International Multiconference on Computer Science and Information Technology, 2010, pp. 709–716.

[10] C.-Y. Lin, S.-F. Chang, Distortion modeling and invariant extraction for digital image print-and-scan process, International Symposium on Multimedia Information Processing (1999) 1–10.

[11] I. Tkachenko, W. Puech, O. Strauss, J. Gaudin, C. Destruel, C. Guichard, Improving the module recognition rate of high density QR codes (version 40) by using centrality bias, in: International Conference on Image Processing Theory, Tools and Applications, 2014, pp. 14–17.