O-006

Expansion of Image Displayable Area in Design QR Code and Its Applications

藤田 和謙 †　栗林 稔 †　森井 昌克 †
Kazuaki Fujita †　Minoru Kuribayashi †　Masakatu Morii †

1 Introduction

Recently, a lot of QR codes [1] [2] are shown in advertising booklets and Web pages to lead users to a particular site. The QR codes are the most popular two-dimentional code in Japan, and can contain more information than bar codes, and the information can be read very quickly by the QR code readers equipped in most cellular phones. Additionally, an error correction capability, which the QR codes have, helps the reading under noisy conditions. From these features, the QR codes are used in versatile purpose. However, because of the random geometrical patterns in the QR code, its low artistic quality becomes a problem for some applications. In order to improve the artistic quality of the QR codes, design QR codes have been invented. The inventions of the design QR codes can be generally classified into two types. Some intentionally modify several bits of an original QR code within the possible the error correction capability, and the others change the padding symbols to produce a specific designed image on the QR code. However, the exploitation of the error correction capability for design degrades the readability of the design QR codes, and the possible area in which the designed image is embedded is restricted due to the standardized structure of QR code. The main restriction is the systematic encoding of Reed-Solomon (RS) code [3].

In this paper, we focus on non-systematic encoding of Reed-Solomon code, and propose a new method for producing a design QR code. The RS code is one of the Maximum Distance Separable (MDS) code. In the MDS code, the codewords derived by non-systematic encoding are mapped to the codewords space of the systematic encoding. As the result, the degree of freedom of encoding the codewords increases, and we can freely select the designable area in the QR code and can embed a designed image without sacrificing the error correction capability of RS code. In addition, for embedding a clear and high resolution image, we propose the method to improve the visual quality using the QR code decoder. It is noteworthy that our designed QR code can be read by the QR code readers equipped in cellular phones.

2 QR Code

QR code(quick response code), a kind of two two-dimentional code, can contain more information than one dimension bar code. QR code has the tolerance for the wound and dirt, and stored information can be read accurately within a very short time. The information may be text, URL, or other data. Because of these features, QR codes are used on the various purpose.

2.1 Composition of QR code

A QR code consists of black modules arranged in a square pattern on a white background. The module represented by black or white pattern is the minimum component of a QR code. The size of the QR code is determined by a version number from 1 to 40. Because of the quality of camera devise equipped in a cellular phone, it is difficult to read a QR code with version more than 20. The number of modules representing an encoded data in a QR code of version n is $17 + 4n$. The QR code uses the Reed-Solomon(RS) code for error correction which capability is classified into 4 levels: L, M, Q, and H in the increasing order. Each error correction level can correct symbols up to about 7 %, 15 %, 25 % and 30 % to all symbols of the QR code.

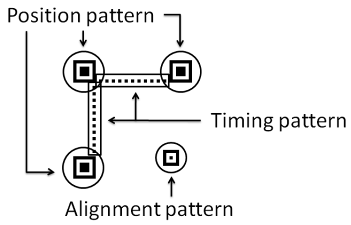


Fig.1 Function patterns.

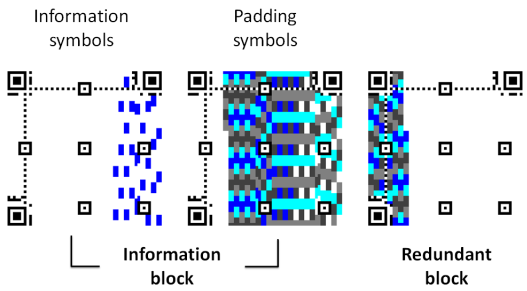


Fig.2 Positions of each symbol in a 10-L QR code.

The QR code has function patterns in order for a reader to identify the position in which an encoded data is involved. The patterns are composed of three main parts; position pattern, alignment pattern, and timing pattern. Figure 1 shows these function patterns of version 5 QR code.

Because of the characteristic of the RS code, each symbol of the codeword is composed of 8 bits, and it is arranged by successive 8 modules in a QR code. Considering a dirt on a QR code, the symbols of the codeword are arranged not in a successive order, but in an interleaved one.

Given the version number and the error correction level, the number of codewords and their constructions expressed by (n, k, d) is uniquely determined in a QR code, where n, k, d mean the code length, the number of information symbols, and the minimum distance satisfying $d = n - k + 1$. For example, 5-L or less QR codes are composed by a single codeword, while 5-M or more QR codes are composed by two or more codewords and they are set by an interleaved order. The code length n is increased with the version number, while k is decreased with the error correction level. Since each symbol of the codeword is composed of 8 bits, at most $8k$ bits (k bytes) is represented by a single codeword. For 5-M or more QR codes, the amount of total information to be embedded, namely the capacity, is the multiple of $8k$. If the amount of infor-

† 神戸大学大学院工学研究科，Graduate School of Engineering Kobe University

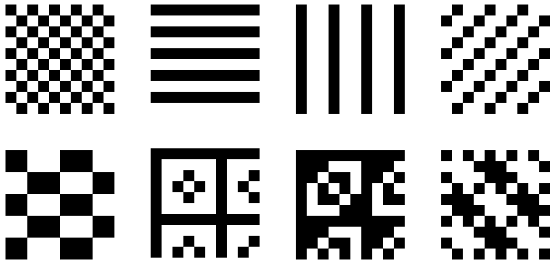


Fig.3 Eight masking patterns.

Fig.4 DesignQR([4].)

Fig.5 QR-JAM([6].)

mation to be embedded is less than the capacity, padding symbols are attached with the information symbols. For convenience, we call ”information block” the information symbols attached with the padding symbols. The padding symbols has no information, so it can be changed freely. The remaining $n - k$ symbols are called parity symbols in a RS code, and its redundancy contributes on an error correction capability. In the systematic encoding, the parity symbols are derived uniquely from the symbols in an information block. We call ”redundant block” the parity symbols. Figure 2 shows positions of each symbol in the 10-L QR code. The information symbols are 27 bytes and each symbol is set by the interleaved position as Figure 2.

It is desirable to balance the number of black and white modules considering the characteristic of a QR code reader. Before arranging the encoded data, a specific masking pattern is operated with the data by XOR for balancing the number. Here, it is strongly required for the masking pattern to avoid the function patterns appearing at the masked data because it causes misreading of positions of the QR code. So, among 8 masking patterns shown in Figure 3, an encoder selects the best pattern considering the above restriction.

2.2 Conventional Method

For commercial applications, an artistic quality of QR codes has been improved by designing a particular image within the code. Such a QR code is called “design QR code”. The studies of the design QR code can be generally classified into two approaches. One intentionally modifies several bits of original QR code within the possible error correction capability. The others change the padding symbols to produce a specific designed image on a QR code. The designQR [4] and the LogoQ [5] use the former approach, and the QR-JAM [6] and the method in [7] use the latter one.

In the former approach, the error correction level should be the highest H or the second highest M, in order to ensure the size of area at which a particular image is displayed. Then the design image, whose size is less than the limited size of error correction capability, is simply pasted on the QR code without covering the function patterns. The size of pasting area is at most the number of bits what the applied RS code can correct. For example, the size of the area is 216 bytes for 15-H QR codes. Thanks to the simplicity in the construction, it is very easy to implement this method. Figure 4 shows an example produced by the designQR. However, this method has the following drawbacks. The amount of information involved in the design QR code is small because the error correction level is high. Furthermore, the design QR code is more difficult to read than a non-designed QR code because it sacrifices the error correction capability for designing image. Although the LogoQ suppresses the use of the error correction capability by keeping the original states of black and white, its readability is still degraded from a non-designed OR code.

The latter approach uses the padding symbols, which has no information and can be changed freely, during encoding the codewords. By changing the information block, the approach is independent with the error correction capability. A free software of the QR-JAM MAKER is open to the public, but it is limited to 5-L QR codes and the amount of data is small. Figure 5 shows an example produced by the QR-JAM MAKER. In [7], each module is divided into four sub modules to improve the resolution of displayed image. The size of the designable area is $k - i$ bytes, where i is the size of encoding data. For example, in 15-L QR code, k is 523 bytes and the size of the designable area is $523 - i$ bytes. However, the designable area is pretty limited because the padding symbols are placed on the middle of the QR code in the systematic encoding of the RS codewords. And the area of the redundant block cannot be designed because the redundant block is uniquely decided by the corresponded information block.

3 Non-Systematic Encoding of RS Code

In this paper, we introduce a non-systematic encoding of RS code for solving the problems of conventional methods. In the systematic encoding, the parity symbols are uniquely decided by the information symbols. Thus, the positions of the information blocks and the redundant block are basically fixed in a QR code.

It is well-known that the RS code is a MDS (Maximum Distance Separable) code. The MDS code satisfies the singleton bound with equal sign, so in the linear code (n, k, d), a formula $d_{min} = n - k + 1$ holds. In the MDS code, a codeword encoded by the non-systematic encoding is one of the codewords encoded by a systematic encoding. And therefore, QR codes encoded by the non-systematic encoding also can be read with common QR code readers. In the non-systematic encoding, there are ${}_nC_k$ candidates for generating a codeword from k information symbols. If k symbols selected freely from n symbols are regarded as the information symbols attached with the padding symbols, the remaining $n - k$ symbols are decided as the parity symbols. Without the restriction of the designable area in the conventional methods, we can display an image on the redundant block by assigning padding symbols at the block because we can also freely change the padding symbols in this case. When the amount of encoding data is small, the designable area becomes large in the method. If a QR code has m codewords expressed by $C_a(n_a, k_a, d_a)(1 \leq a \leq m)$, and the size of the information symbols is i bytes, the size of designable area is $(\sum_{a=1}^{m} k_a) - i$ bytes.

4 Proposed Method

In this session, we propose the methods to create design QR codes by non-systematic encoding. There are three methods depending on the applications. In the following, we assume that our design QR code has m RS codewords and contains i bytes information and each symbol expressed by $C_a(n_a, k_a, d_a)(1 \leq a \leq m)$.

4.1 Design All Area

It is possible to design all area of QR code if a small error is accepted for a design QR code from the artistic quality point of view. The encoding area, excepting for excepts function patterns, is used as designable area. According to an image to be embedded in a QR code, we select RS codewords which hamming distances from the modules representing for the image are small. However, the image is not always represented by RS codewords, but is containing small errors defined as different modules which are different from the modules generated by design image. So, we generates some candidates codewords by changing the position of information symbols, and choose the best codeword whose hamming distance is minimum. We call this method "method 1". The procedure to make design QR codes is described as follows;

- step1. Assign pixels of the image to modules of a QR code, and binarize the modules with the threshold determined by the average of all RGB values.
- step2. Operate a predetermined masking pattern to the binarize image, and replace i symbols of the masked image with an information symbols, which are never changed in the following steps.
- step3. Partition the masked image into m sequences which are corresponding to the RS codewords placed on the QR code in an interleaved order. We denote the m sequences by $\boldsymbol{b_a}$, $1 \leq a \leq m$
- step4. For $1 \leq a \leq m$, perform a subroutine SelectRS($\boldsymbol{b_a}$) to find the best RS codewords whose Hamming distance from $\boldsymbol{b_a}$ is minimum.
- step5. Operate the predetermined masking pattern again to cancel the masking operation at step2.

Figure 6 shows the masking by a mask pattern 0. Remasking operation using the same masking pattern keeps the artistic quality of the designed image.

In the subroutine SelectRS(), we generate N codewords and choose the best one. It is noticed that the expectation of a Hamming distance between $\boldsymbol{b_a}$ and a randomly selected RS codeword is $4n_a$. By initializing parameters $x = 1$, and $H_a = 4n_a$, the subroutine SelectRS() is described as follows;

- step s1. Select k_a symbols at random from $\boldsymbol{b_a}$, and generate the remaining $n_a - k_a$ symbols by the non-systematic encodeing. We denote the generated RS codewords by $\boldsymbol{C_{a,x}}$.
- step s2. Calculate the Hamming distance $H_{a,x}$ between $\boldsymbol{C_{a,x}}$ and $\boldsymbol{b_a}$.
- step s3. If $H_{a,x} < H_a$, store the codewords $\boldsymbol{C_{a,x}}$ as a candidate and replece $H_a = H_{a,x}$.
- step s4. Increment $x = x + 1$
- step s5. If $H_a = 0$ or $x = N$, terminate this subroutine; otherwise, go to step s1.

4.2 Design Optional Area

By restricting a size of the designable area, we can generate a design QR code with no different modules. The size is larger than that of the conventional method using the error correction capability. And, in comparison with the conventional method using the padding symbols, we have much more freedom for displaying an image on a QR code. We call this method "method 2". By gathering the padding symbols in one area, the designable area can be selected freely. From the symbols in the designable are, the other symbols are calculated by the non-systematic encoding. Considering the property that the information stores from the right-hand corner of the QR code, it is efficient to place the designable area on the left side of the QR code. The procedure of the method 2 is to perform the same operation as the the method 1 except for the subroutine SelectRS(). So we only describe the modified subroutine as follows;

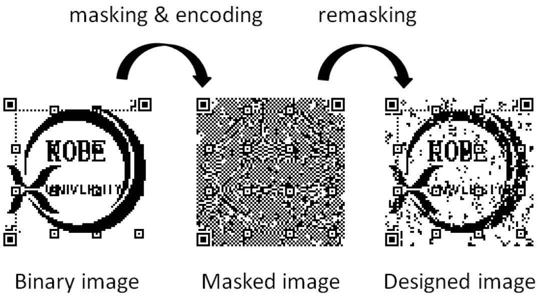


Fig.6 Mask Canceling Operation.

- step s′1. Decide freely the designable area whose size is smaller than $(\sum_{a=1}^{m} k_a) - i$ bytes.
- step s′2. Select k_a symbols from $\boldsymbol{b_a}$ whose symbols are involved in the designable area, and generate the remaining $n_a - k_a$ symbols by the non-systematic encoding.

4.3 Improvement of Resolution

In both methods, the resolution of an image to be displayed gets down by the binarizing operation at step 2. So, images, containing complex patterns and characters, are unsuitable for these methods. In order to solve the problem in the method 2, we improve the resolution of the design QR code without the different modules. We propose the method to create the design QR code by using the QR code decoder in the binarizing process. If the designed area of a produced design QR code is pasted by the original high-resolution image, the modules read at the step 2 by the decoder are atmost same as those of the pasted area. Because it is expected to read the same modules from the design QR code with high-resolution image as that of the code produced by the method 2. Therefore, the displayed image can be replaced by the original high-resolution image. We call this method "method 3". The procedure is to add a pre-processing and a post-processing to that of the method 2, except for the binarizing in step 1.

The pre-processing is as follows;

- Overlay the function patterns on an image.
- Binarize the overlaid image by an open source QR code decoder [8].

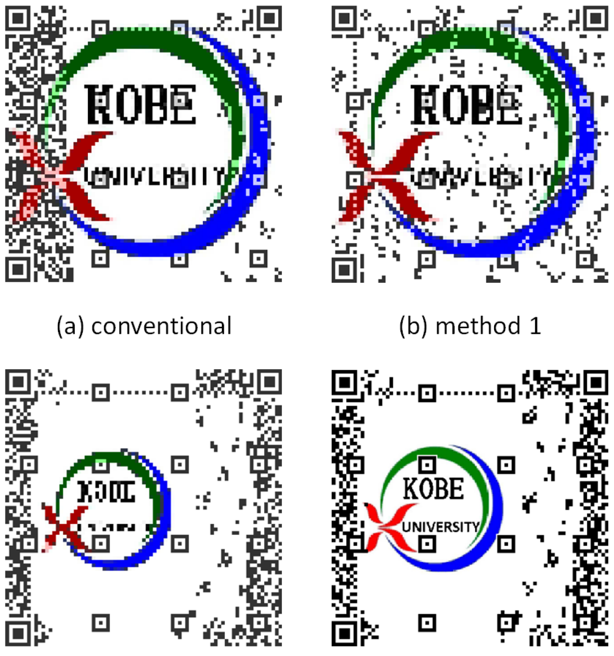
The post-processing is as follows;

- Replace the designed area expressed by the unit of modules by the original image.

5 Experimental Result

5.1 Evaluation

We generate four design QR codes with version 15-L whose embedded data is a text "http://www.kobe-u.ac.jp/". Figure 7(a) is produced by the method of using the padding symbols [6]. Figure 7(b) shows the design QR code generated by the method 1, where the number of candidates is $N = 1,0000$. Figures 7(c) and 7(d) are produced by the method 2 and 3, respectively. Comparing the method 2, the displayed image of the method 3 is clear. Because of the replacement with the original high-resolution image. From these figures, we see that, in the proposed methods, the degrees of freedom and the size of the designable area are improved from those of the conventional methods. From the above reasons, we



(a) conventional (b) method 1

(c) method 2 (d) method 3

Fig.7 Examples of designed QR codes.

Table 1 Relationship between the error correction level and the degrees of freedom in 15 QR codes, where # is the number of the codewords.

level	$(n, k, n-k+1)$	#	freedom
	(109,87,23)	5	6.09×10^{22}
L	(110,88,23)	1	7.53×10^{22}
	(65,41,25)	5	3.97×10^{17}
M	(66,42,25)	5	6.24×10^{17}
	(54,24,31)	5	1.40×10^{15}
Q	(55,25,31)	7	3.09×10^{15}
	(36,12,25)	11	1.25×10^{9}
H	(37,13,25)	7	3.56×10^{9}

can say that the proposed methods have more utility than the conventional methods.

In the methods, the size of the designable area is $(\sum_{a=1}^{m} k_a) - i$ bytes. Under a same version, the QR codes with the error correction level L have the largest designable area. Because k_a becomes maximum for level L. Table 1 shows the relationship between the error correction level and the freedom of the code generation in 15 QR codes. The number of the codewords is increased with the error correction level, while the freedom of the code generation is decreased. From the above facts, the error correction level L should be applied for the proposed methods.

5.2 Consideration

We consider our methods by comparing the conventional methods. In the following, we assume that our design QR code has m RS blocks and contains i bytes information and each symbol expressed by $C_a(n_a, k_a, d_a)(1 \leq a \leq m)$. Comparing the conventional method using the error correction capability, the proposed methods have larger size of the designable area. In the conventional method, the size of the designable area is limited to the maximum of the error correction capability, expressed by $\sum_{a=1}^{m}(d_a - 1)/2$ bytes. However, proposed mehods have $(\sum_{a=1}^{m} k_a) - i$ designable area, and usually $\sum_{a=1}^{m}(d_a - 1)/2 < (\sum_{a=1}^{m} k_a) - i$ holds. In addition, the conventional method has already used the error correction capability for displaying an image on the QR code. In contrast, methods 1 and 2 inherit the original error correction capabilities. On the other hand, the QR code generated by the method 3 has some errors, because tiny but non-negligible difference between the binarizing of the design image and that of the generated design QR code is unavoidable at the decoding process. So it is needed to care about the size of overwriting area, but this method is has the same high resolution as this conventional method has.

Comparing the conventional method using the padding symbols, the proposed methods have the same size of the designable area. However, the proposed methods have more freedom in the designable area than this conventional method whose designable area is limited to a fixed padding area.

In summary, the proposed methods resolve the size limitation problem of the conventional method using the error correction capability, and the place limitation problem of the conventional method using the padding symbols. Additionally, the methods 3 further solves the resolution problem that the the conventional method using the padding symbols, method 1 and 2.

6 Conclusion

In this paper, we proposed a new method to produce a design QR code by introducing the non-systematic encoding of RS codewords. We can freely display an image on a QR code without sacrificing the error correction capability. Depending on applications, the image can be displayed on the entire QR code excepting the function patterns. In the proposed methods, the error correction level L is the best for design. Using a QR code decoder at the generation of a design QR code, we can improve the artistic quality of the displayed image. The design QR code generated by the proposed methods can be read with the QR code readers equipped in cellular phones.

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