# A New Aesthetic QR Code Algorithm Based on Salient Region Detection and SPBVM

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## Abstract

Many aesthetic QR code algorithms are proposed. In this paper, a new aesthetic QR code algorithm, based on salient region detection and Selectable Positive Basis Vector Matrix (SPBVM), is proposed. Firstly, the complexity of texture features are added to calculate the saliency values of the image, based on the existing salient region detection algorithms. According to the saliency map, the important area of the image is preserved for the subsequent beautification operation. Then, the appropriate basis vectors are selected by using the proposed SPBVM according to the acquired salient region, and the salient region is displayed completely by XOR operation which is performed by the original QR code and the selected basis vectors. Finally, the aesthetic QR code is obtained by combining the background image and original QR code. The results show that the proposed algorithm can produce more accurate salient area and have more pleasant visual effects.

Keywords: Aesthetic QR code, RS code, Salient region detection, Selectable positive basis vector matrix, XOR operation

## 1 Introduction

QR code is a kind of two-dimensional code which has the characteristics of high error tolerance level, wide range of encoding information types as well as convenient and fast reading speed. With the development of smart phones and mobile terminals, consumers can use the QR code to browse information and go shopping anytime and anywhere. For example, one can complete the payment by scanning the QR code with Alipay, get the interpretation of tourist attractions by scanning the QR code with a variety of related APPs. It not only saves the cost of enterprises but also brings great convenience to consumers. At present, QR code is encoded based on RS error correction coding mechanism, thus it can still be decoded correctly even if the image is damaged partly [1]. The traditional QR code is composed of black and white modules, and it is difficult to distinguish among different QR codes which all have single color and poor visual effect. Therefore, in recent years, many researchers have focused on the algorithm of aesthetic QR code in order to solve the above problems.

The current aesthetic algorithms can be grouped into two categories. The first category modifies the color or shape of the module in the original QR code to achieve the beautification effect. The results are shown in Figure 1.



**Figure 1.** Modifying the color or shape of the modules

The algorithms in second category consider the fusion of the original QR code and background image to enhance the visual effects. Because the QR code is encoded by the coding mechanism of RS code, the algorithm can be divided into two kinds of algorithms according to the characteristics of RS code [2-3].

The first kind of algorithms make use of the error correction encoding mechanism of RS code [4-6, 9]. The effect pictures are shown in Figure 2.

Li et al. [6] mainly used the RS error correction coding principle and the characteristics of QR code, combined with the salient region detection of background image, to display the important region of the image as completely as possible. The experimental results show that there are no black and white modules in the face area of the image, and the salient region is almost completely displayed. However, in this algorithm, the error correction capacity of RS code is limited by the version and error correction level of QR code, and the salient region is always limited to the center of the image. The algorithm cannot be applied to the background image with multiple salient regions.

(a) The effect picture of [4]

(b) The effect picture of [5]

(c) The effect picture of [6]

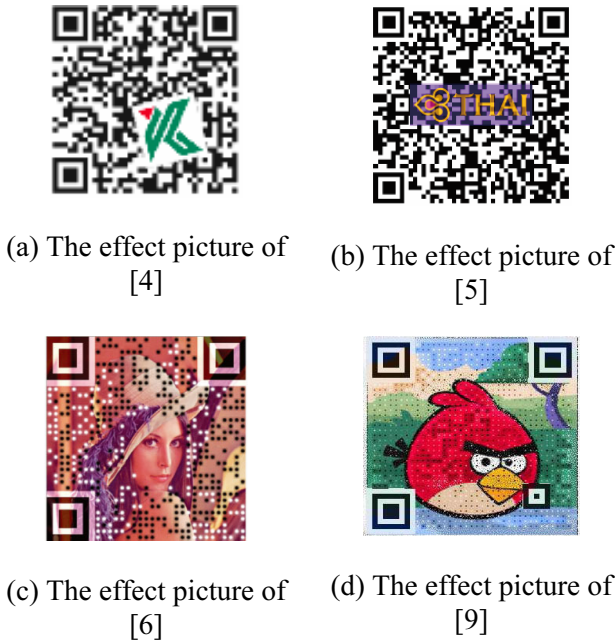(d) The effect picture of [9]

**Figure 2.** The aesthetic QR codes of different

Garateguy et al. [9] introduced an automatic method to generate aesthetic QR code. The method encoded the QR information into the luminance values. They utilized halftoning masks for the selection of modified pixels and nonlinear programming technique to optimize luminance levels locally. Visual distortion is reduced in this way. However, the processed image is covered with a lot of the black and white points and the visual effect of salient region is poor.

The second kind of algorithms uses the XOR characteristic of RS code [7-8] to beautify the QR code. The effect pictures are shown in Figure 3.



(a) The effect picture of [7]

(b) The effect picture of [8]
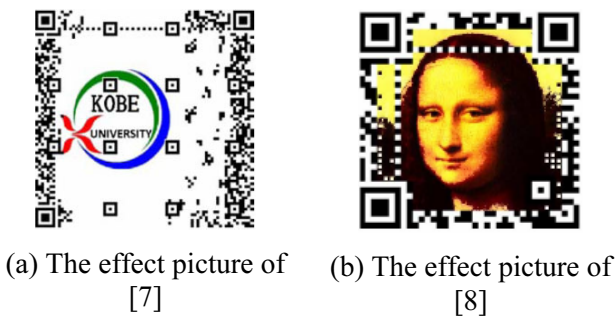
**Figure 3.** The aesthetic QR codes of different algorithms

Lin et al. [8]0 proposed two steps for aesthetic QR code. First of all, the XOR characteristic of RS code was used to select the control bits to generate a baseline QR code with black and white modules. Then, a rendering mechanism was applied to beautify the QR code, so that the visual differences between the aesthetic QR code and background image can be reduced as much as possible. The overall visual effect is good, but there are many black and white modules in the edge region of the aesthetic QR code. The salient region of selected image is also limited in the center position.

Although the above algorithms have implemented the beautification of the visual appearance of the traditional QR code, the visual effect is more and more in line with people's aesthetic requirements. But the selected images for aesthetic QR code is relatively simple, the algorithms cannot be well applied to the background image with multiple salient regions.

Considering the above disadvantages, we proposed a new algorithm for aesthetic QR code by using the XOR characteristics of RS code with the proposed SPBVM, and combining with the salient region detection, which are introduced as follows.

(1) A salient region detection algorithm is proposed to obtain a saliency map which is more suitable for the aesthetic QR code. The complexity of texture features is calculated by the Gray Level Co-Occurrence Matrix (GLCM) and added into the salient region detection algorithm of Xu et al. [10], and the saliency map can be obtained more accurately. A closed binary image is generated by binary processing and dilation and erosion algorithm, which is convenient for the selection of the basis vectors.

(2) SPBVM is constructed according to the saliency map from Positive Basis Vector Matrix (PBVM), which can be used to realize the flexible replacement of regions. In QR code encoding, there are much more code words in data area than parity area. The total number of basis vectors corresponding to the code words in data area are greater than the bits of parity area. The basis vectors corresponding to the code words in data area are redundant in the process of Gauss Jordan Elimination. Therefore, based on the saliency map, some positive basis vectors can be selected to form SPBVM, and the associated Reverse Basis Vector Matrix (RBVM) can be obtained by Gauss Jordan Elimination. With the RBVM, the replacement in parity area will have no effect on the display of the black and white modules in salient area. Therefore, the display of salient region is retained as much as possible.

## 2　The Proposed Algorithm

In this section, a new algorithm of aesthetic QR code based on the improved salient region detection and the proposed SPBVM will be described.

Given a background image $I_O$, we intend to make the salient region of $I_O$ in the aesthetic QR code $I_R$ be fully displayed, and not affect the decoding rate. Firstly, the salient region of the selected background image $I_O$ is obtained by the improved salient region detection algorithm. The complexity of texture features in background image is added to calculate the saliency values, and the saliency map $I_{SAL}$ is generated. Then the binary image with closed area $I_{BIN}$ is obtained by dilation and erosion algorithm. It is convenient for the

selection of basis vectors. Secondly, the proposed SPBVM is used to generate the initial aesthetic QR code. According to the extracted salient region, the result of RBVM $I_{RR}$ is generated by XOR operation between $I_{BIN}$ and the selected basis vectors which include in the SPBVM. Finally, the aesthetic QR code $I_R$ is generated by the synthetic strategy with $I_{RR}$ and $I_P$. Figure 4 shows the flowchart of the proposed aesthetic algorithm.
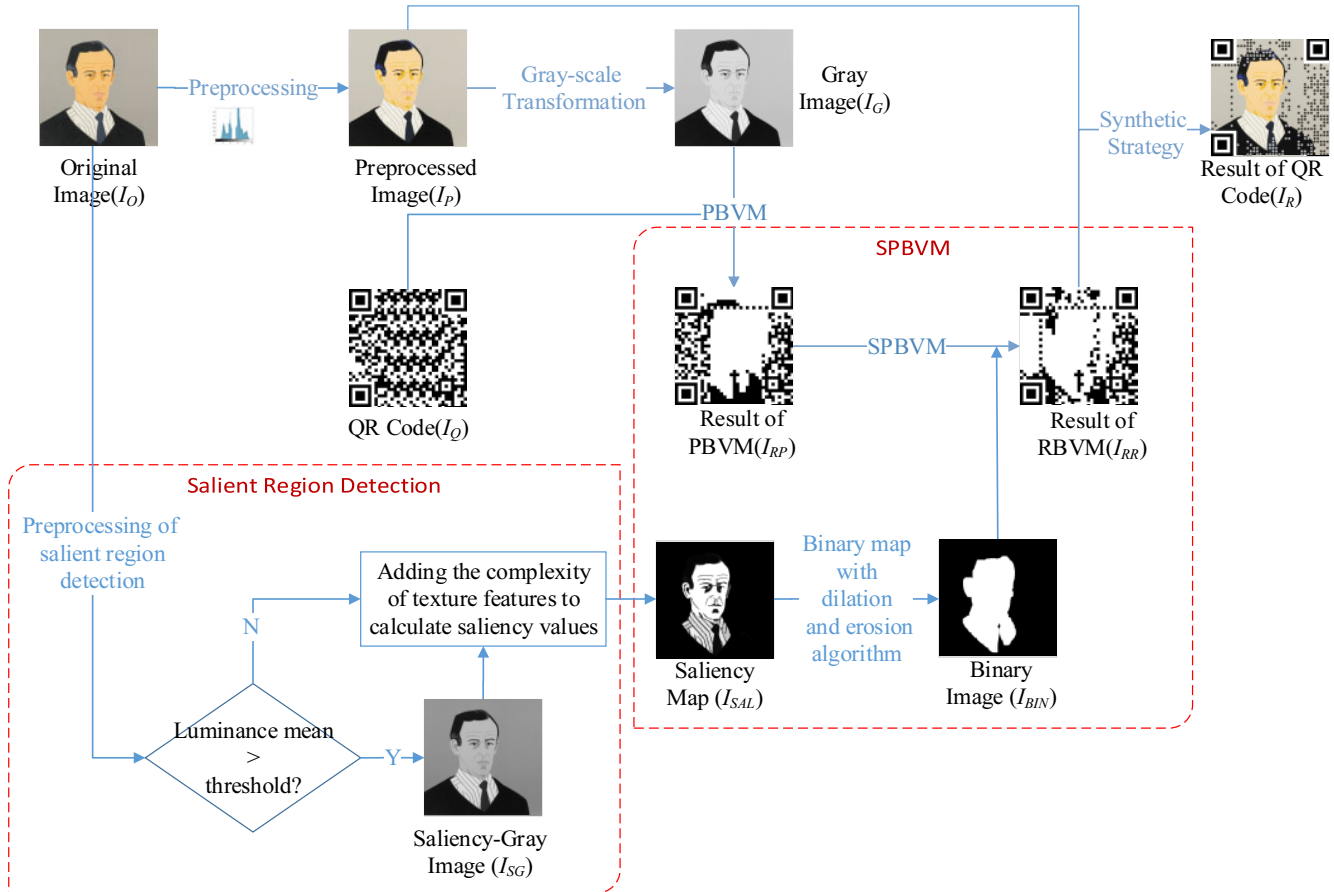


**Figure 4.** Flowchart of the proposed algorithm

## 2.1 The Improved Salient Region Detection Algorithm

It is well known that the decoding rate of QR code depends on the conversion of the color of the modules with decoder, and the background color of salient region has an influence on the decoding of black and white modules. In the previous works, without taking into account of the salient region of the background image, there are black and white modules in the salient area of the final results, which will result in error detection and lower decoding rate. Therefore, the salient region detection algorithm is added to the aesthetic QR code algorithm in this paper. Because the black and white modules of aesthetic QR code cannot lie in the salient region, the influence of background image for decoding will be reduced.

In this paper, the salient region detection algorithm is improved on the basis of Xu et al. [10] and Cheng et al. [11]. In the previous algorithm, the brightness variation of the elements is taken into account. However, it ignores the situation where the brightness

of the non-salient region changes greatly, the non-salient region is mislabeled as a salient region, resulting in inaccurate detection results. Considering that the salient region has richer texture, the texture in non-salient region is however relatively simple and smooth. Therefore, by adding the complexity of texture features in each region, the more accurate salient region can be achieved

### 2.1.1 The Description of the Complexity of Texture Features

The Gray Level Co-occurrence Matrix (GLCM) [12-15] is used to calculate the complexity of texture features in this paper. Considering the computational performance and the time consuming, five texture parameters (energy, entropy, contrast, homogeneity, correlation) are selected in the salient region detection algorithm, and the saliency map can be applied to the aesthetic QR code. The complexity of texture features is calculated by the five parameters of the diagonal direction which are shown in the equation (1).

$$G_{R_k}^{com} = a_1 * Energy + a_2 * Entropy + a_3 * Contrast$$
$$+ a_4 * Homogeneity + a_5 * Correlation \qquad (1)$$

In the equation (1), $a_1$, $a_2$, $a_3$, $a_4$ and $a_5$ denote the weight coefficients, which are calculated based on the BP neural network in Chen et al. [16]. *Energy* represents the distribution of grayscale image and the thickness of the texture, in equation (2). *Entropy* represents the amount of information in the image, in equation (3). *Contrast* reflects the comparison of the brightness between a pixel value and its neighborhood pixel values, in equation (4). *Homogeneity* represents the local changes of the texture, in equation (5). *Correlation* represents the conformity of the texture in different directions, in equations (6)-(10).

$$Energy = \sum_{i=1}^{n} \sum_{j=1}^{n} G(i,j)^2 . \qquad (2)$$

$$Entropy = -\sum_{i=1}^{n} \sum_{j=1}^{n} G(i,j) \log_2 G(i,j) . \qquad (3)$$

$$Contrast = \sum_{i=1}^{n} \sum_{j=1}^{n} (i-j)^2 G(i,j) . \qquad (4)$$

$$Homogeneity = \sum_{i=1}^{n} \sum_{j=1}^{n} 1/(1+(i-j)^2) * G(i,j) . \qquad (5)$$

$$Correlation = \sum_{i=1}^{n} \sum_{j=1}^{n} ((i*j)G(i,j) - u_1 u_2)/s_1 s_2 . \qquad (6)$$

where

$$u_1 = \sum_{i=1}^{n} \sum_{j=1}^{n} i * G(i,j) . \qquad (7)$$

$$u_2 = \sum_{i=1}^{n} \sum_{j=1}^{n} j * G(i,j) . \qquad (8)$$

$$s_1^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} G(i,j) * (i-u_1)^2 . \qquad (9)$$

$$s_2^2 = \sum_{i=1}^{n} \sum_{j=1}^{n} G(i,j) * (i-u_2)^2 . \qquad (10)$$

### 2.1.2 The Flowchart of Salient Region Detection Algorithm

The improved salient region detection algorithm is described in details as follows:

Step 1: In order to make the results of the salient region more suitable for the selection of the basis vectors, the background image has to be preprocessed. The luminance mean of the image is calculated to compare with the fixed threshold. If the luminance mean is greater than the threshold, the image will be converted to grayscale image.

Step 2: The image is divided into different regions by the segmentation algorithm.

Step 3: The complexity of texture features is calculated as a detection factor of the salient region.

Step 4: The salient values are mapped to each pixel of the corresponding region. That means the salient value of the pixels in the same salient region will be the same.

Step 5: The binary map of salient region is obtained by Otsu's method [17], and then the dilation and erosion algorithms are used to get a closed area. A closed salient region is more suitable for the algorithm of aesthetic QR code.

The saliency values are calculated by the equation (11).

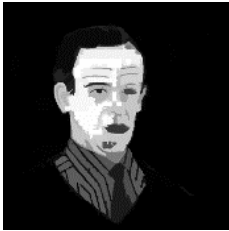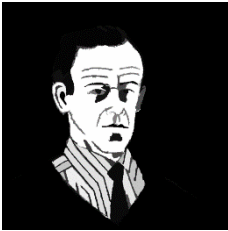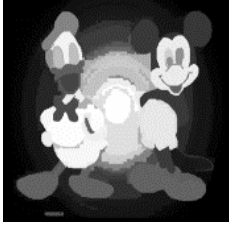$$S(R_k) = G_{R_k}^{com} L_{R_k} \sum_{r_k \neq r_i} e^{D_s(R_k,R_i)/-\sigma_s^2} w(R_i) D_R(R_k,R_i) . \qquad (11)$$
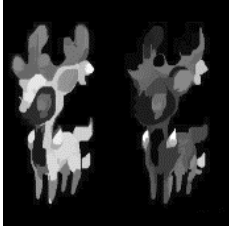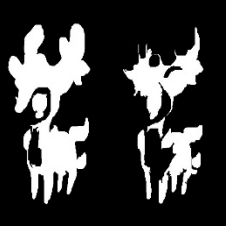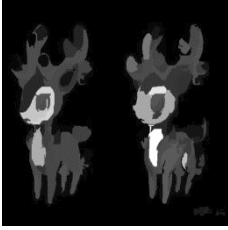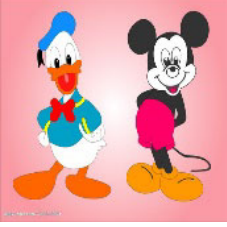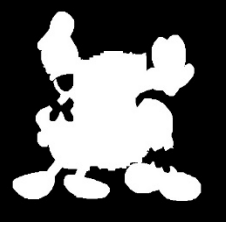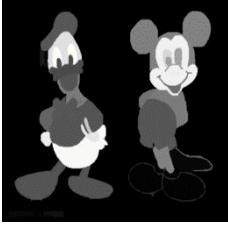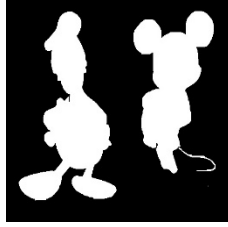
Here, $G_{R_k}^{com}$ is the complexity of texture features; $L_{R_k}$ is the brightness variation of the elements which is calculated by equation (12).

$$L_{R_k} = (\sum_{i=1}^{N(R_k)} C_{R_k}^i)/N(R_k) . \qquad (12)$$

where $C_{R_k}^i$ is the convolution operation of the 3 * 3 neighborhood of the pixel point $i$ in the $R_k$ region with the template [0, -1, 0; -1, -5, -1; 0, -1, 0]; $D_s(R_k,R_i)$ indicates the spatial distance between different regions; $w(R_i)$ represents the weight of the region, determined by the number of pixels; $D_R(R_k,R_i)$ represents the color distance between the regions.

The comparison between the improved salient region detection algorithm and Xu's algorithm in [10] is shown in Table 1. According to the experimental results, it can be seen that the salient region which is obtained by the improved algorithm is more accurate than the Xu's algorithm [10]. It is much better for the non-salient region with strong brightness variations of the image.

**Table 1.** The comparison of different salient region detection algorithms

| Background image | Saliency map of [10] | Binary image of [10] | Saliency map of our algorithm | Binary image of our algorithm |
| --- | --- | --- | --- | --- |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

## 2.2  The Generation of SPBVM

In order to display the salient region as much as possible, we propose the concept of SPBVM. The main purpose is mainly to select the appropriate basis vectors according to the salient region, then the associated RBVM can be conducted by performing XOR operation with Gauss Jordan Elimination algorithm on SPBVM. By applying the replacement method based on RBVM in parity area, there are no black and white modules lying in the salient region of the final aesthetic results.

### 2.2.1  Distribution and Characteristics of RS Code

The RS code can be divided into two parts: data area (the length is $k$) and parity area (the length is $t$), the total length of a RS code is $n$. Among them, the area for storing the input information which is encoded by RS encoding mechanism is called as the valid data area (the length is $m$), and a terminator is added after the information sequence, the code words after the terminator is called as invalid data area (the length is $k$-$m$). The information stored in the invalid data area has

no effect on decoding, so it is often modified to display the background image in the algorithm of aesthetic QR code.

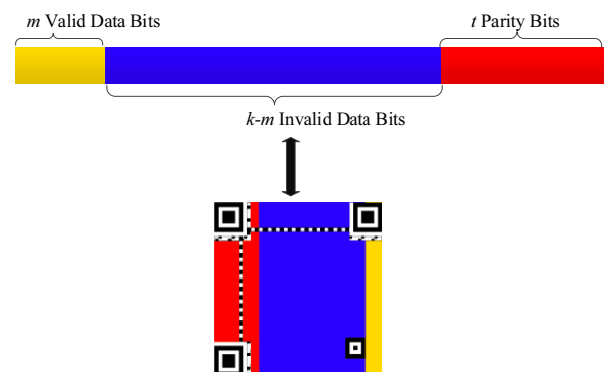The distribution of RS code in QR code is shown in Figure 5.



**Figure 5.** The distribution of RS code in QR code

In [2-3], Cox et al. have proved that the RS code has two important characteristics: (1) The input information can be obtained directly in the encoding

procedure; (2) The XOR operation can be performed in RS code. That is, two different RS codes are transformed into a new RS code by XOR operation. For example, given two RS codes, $RS_1$ = 01001, $RS_2$ = 10010, after the XOR operation, $RS_3$ = RS1 $\oplus$ $RS_2$ = 11011. $RS_3$ is also the legal RS code. Therefore, the XOR operation can be used to reduce the visual differences between the background image and the original QR code without reducing the error correction ability.

## 2.2.2 PBVM and RBVM

RS encoding is closed under XOR and the concept of basis matrix are proposed in [2-3]. The modification of data area is achieved by the closed of RS encoding. The idea is improved by introducing the optimization fusion strategy in [8]. We extend the idea and propose the concepts of PBVM and RBVM, achieving double modification of the QR code, the data area is modified by PBVM and RBVM is used to modify the parity area.

First of all, the positive basis vector $b_i$ is constructed with the former $k$ data bits and the latter $t$ parity bits, only the $i_{th}$ bit is 1 in the data bits, the other bits are 0, and the $t$ bits are the corresponding parity bits of RS code. Each basis vector is a valid RS code where $1 \leq i \leq k$. The all positive basis vectors $b_i$ are represented in Figure 6.
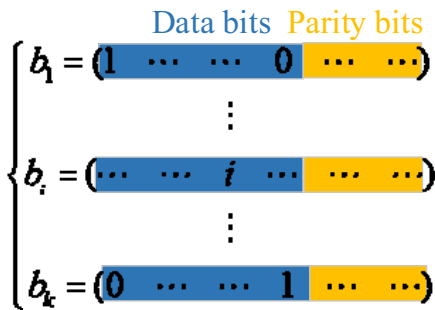


**Figure 6.** The positive basis vector $b_i$

The PBVM is constructed by the positive basis vectors, which is used to modify the data area of RS code. It can be expressed as follows:

$$PBVM = \begin{pmatrix} b_1 \\ b_2 \\ \vdots \\ b_k \end{pmatrix} = (I_k \quad | \quad P). \qquad (13)$$

Where $I_k$ is the $k_{th}$ unit matrix, $P$ with size $k * t$ is the corresponding matrix of parity area. The PBVM in matrix is shown in Figure 8(a).

By performing elimination operation which is similar to the Gauss Jordan elimination on the PBVM, the parity matrix $P$ is simplified to the simplest echelon matrix by row transformation, and the process is described as follows:

$$PBVM \xrightarrow[\text{Transformation}]{\text{Row}} \begin{pmatrix} R & | & I_t \\ & \vdots & \\ 0 & \cdots & 0 \end{pmatrix}. \qquad (14)$$

Thus the RBVM is obtained, which is used to modify the parity area of RS code. It can be expressed as follows:

$$RBVM = \begin{pmatrix} c_1 \\ c_2 \\ \vdots \\ c_t \end{pmatrix} = (I_t \quad | \quad R). \qquad (15)$$

Where $I_t$ is the $t_{th}$ unit matrix, $R$ with size $t * k$ is the corresponding matrix of data area. The RBVM is shown in Figure 8(b).

The structure of RBVM is similar to PBVM, each row is a reverse basis vector $c_j$ where $1 \leq j \leq t$. $c_j$ indicates that the $j_{th}$ bit is 1 in the parity bits and the rest bits are 0. The reverse basis vector $c_j$ is represented in Figure 7.
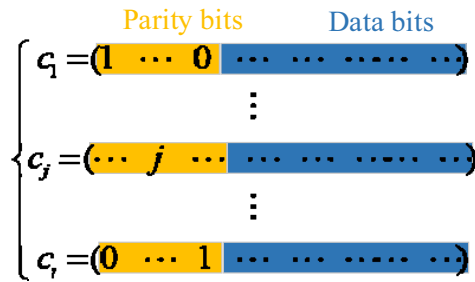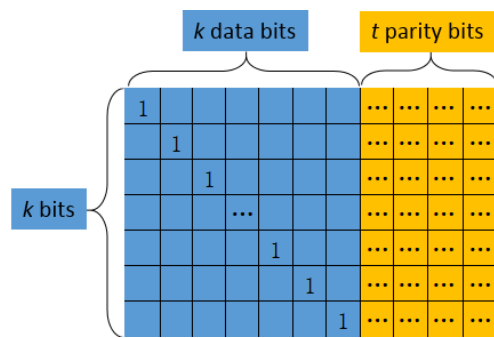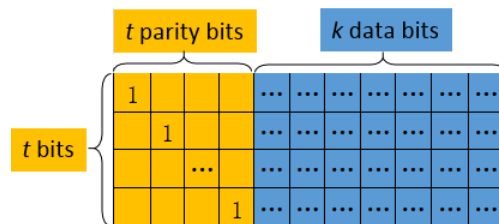


**Figure 7.** The reverse basis vectors $c_j$



(a) PBVM



(b) RBVM

**Figure 8.** PBVM and RBVM

On the basis of the above works, the XOR operation can be performed on the encoded information stream with the generated basis vector matrixes, PBVM and RBVM. It is possible to control only one bit to be modified without changing the other bits. Once the data bit (or parity bit) changes, the corresponding parity bits (or data bits) remain updated simultaneously, so that the result is still a valid RS code without affecting the decoding rate.

### 2.2.3  The Proposed SPBVM

The proposed algorithm will select part of basis vectors in PBVM to construct the SPBVM, and the RBVM which generated by the SPBVM is more suitable for the fusion of background image.

In QR code, the length of data bits $k$ is much larger than the length of parity bits $t$, so it is possible to select parts of basis vectors ($b_{i1}$, $b_{i2} \cdots b_{ij} \cdots b_{il}$, where $il > t$ and $1 \le ij \le k$) to participate in the elimination process. Therefore, a matrix called SPBVM is composed of the partial basis vectors selected from all basis vectors. According to the characteristics of human vision, the salient regions of background image are not expected to be modified. Therefore, the selection scheme of

SPBVM combined with the salient region detection algorithm is proposed. First, the salient region detection is carried out. Then the corresponding basis vectors which is not in the salient region is selected to form SPBVM.

The different RBVM can be obtained according to the different SPBVM by the method which is similar to Gauss Jordan elimination.

According to the coding mechanism of QR code, each black module or white module corresponds to the 0 or 1 bit in the RS coding. A row of basis vectors in the PBVM is selected to modify one designated bit which corresponds black or white module of the original QR code, where the bit with value 1 is reversed, and the bit with value 0 is unchanged. If we select some particular basis vectors, so that the modified bits are located in the non-salient region of background image. That is, the selection of bits can be controlled. To this end, the salient region or non-salient region can be extracted for a particular background image, thus it can provide a baseline for the selection of the basis vectors.

A simple example of the selection of basis vectors in SPBVM is shown in Figure 9.
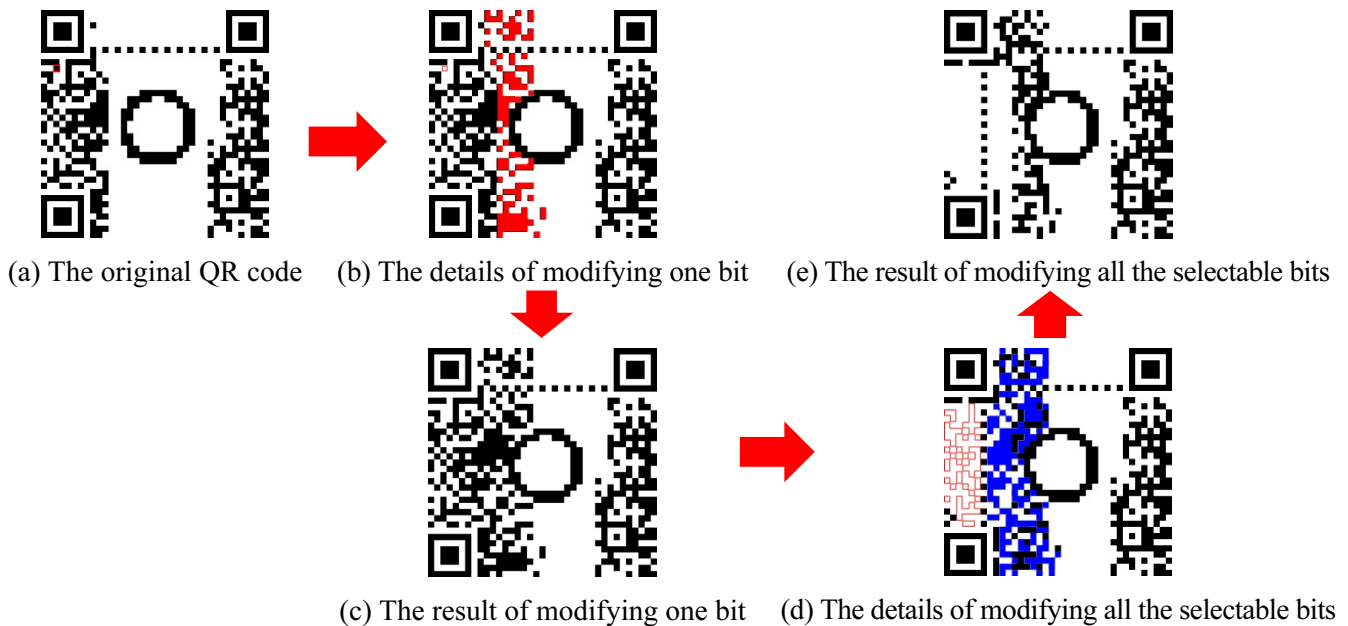


(a) The original QR code  (b) The details of modifying one bit  (e) The result of modifying all the selectable bits

(c) The result of modifying one bit  (d) The details of modifying all the selectable bits

**Figure 9.** The application of SPBVM

In Figure 9(a) The original QR code is obtained, and the circle is the salient region. Figure 9(b) Showing the details of the modification where the modified bit is represented by red box at the upper-left, and the affected code words are represented by red blocks. Figure 9(c) The result of modifying one bit in parity area of (a). (d) Showing the details of the modification on the basis of Figure 9(b). All the bits in selectable basis vectors are modified, and the modified bits are represented by red boxes, the affected code words are represented by blue blocks. Figure 9(e) The result of modifying all the selectable bits. From the experimental

results, we can see that the code words which affected by the modified bits all lay in the non-salient region.

### 2.3  The Description of Algorithm Steps

The algorithm based on salient region detection and SPBVM is proposed for beautifying QR code in this paper. The beautification process is described as follows:

Step 1: The salient region of the background image is obtained by the algorithm in section 2.1.

A background image is transformed into gray image

if its luminance mean is larger than a threshold. Then the complexity of texture features is added to calculate the saliency values. The saliency map is generated and transformed into a binary image with closed area by Otsu's method and the dilation and erosion algorithm. The closed area is ready for the following operations.

Step 2: The binary image of aesthetic QR code is generated by combining the salient region and the SPBVM.

The background image is preprocessed by compressing the pixels which are closed to the threshold in luminance channel for increasing the decoding rate, and the threshold is calculated by Otsu's method. Then the preprocessed image is transformed into a gray image to compare with the original QR code module by module, a binary image of aesthetic QR code can be obtained with PBVM. Then we can construct SPBVM by selecting the positive basis vectors from PBVM according to the binary image of saliency map, and the associated RBVM is generated by XOR operation on SPBVM. It can be used to modify the parity area in QR code.

Step 3: The application of synthetic strategy.

To improve the visual quality after the above-mentioned operations, the synthetic strategy, which is proposed in [6], is used to achieve the fusion of background image and the QR code. The equation is described in (16).

$$Q = \begin{cases} 0, & T_i < T_0 \cap N_i = 0, \\ -1, & T_i > T_0 \cap N_i = 0, \\ 1, & T_i < T_0 \cap N_i = 1, \\ 0, & T_i > T_0 \cap N_i = 10 \end{cases}. \qquad (16)$$

Where $Q = 0$ represents that the module is replaced completely by the background image. $Q = -1$ or 1 represents that the central area of the module is replaced by the corresponding area of the QR code, the other area of the module is replaced by the background image. And $T_i$ represents the gray average value of the gray block, $T_0$ represents the binary threshold, $N_i$ represents the module of QR code, $N_i = 1$ is the white module, and $N_i = 0$ is the black module.

## 3 Experimental Results

A dataset containing 100 images with different styles is ready for experiments. All the images in the dataset are used as background images to generate the aesthetic QR codes, and some results generated by our method are shown in Table 2. For all the aesthetic QR codes, the version number is 5 and error correction level is L.

**Table 2.** The aesthetic QR code generated by our algorithm

## 3.1 Comparison with and without Salient Region Detection

In this paper, we proposed a new aesthetic QR code algorithm by considering the salient region of the image, thus we conducted an aesthetic QR code generation contrast experiment, with salient region detection and without salient region detection. The experimental results are shown in Table. 3.

**Table 3.** The generation of aesthetic QR codes with and without saliency region detection



| Background image | Without salient region detection | With salient region detection |
| --- | --- | --- |

From Table 3, we can see that the proposed algorithm can highlight the important area of the image and has more pleasant visual effect.

## 3.2 Correctness of QR Code Decoding

We evaluated the correctness of decoded messages on three different mobile devices (HUAWEI Honor 7, MI 5, iPhone 6) with three various QR code decoders (WeChat, Qrcode Scanner, Wo Cha Cha). The images in Table 2 which are generated by our algorithm are used to calculate the decoding rates. The results are reported in Table 4. The experimental results show that the aesthetic QR codes have a short response time and high decoding rates.

**Table 4.** Decoding rates on different mobile devices

| Mobile Phone | APP | Decoding Rates |
| --- | --- | --- |
| HUAWEI Honor 7 | WeChat | 100% |
| | Qrcode Scanner | 100% |
| | Wo Cha Cha | 94% |
| MI 5 | WeChat | 100% |
| | Qrcode Scanner | 100% |
| | Wo Cha Cha | 94% |
| iPhone 6 | WeChat | 100% |
| | Qrcode Scanner | 100% |
| | Wo Cha Cha | 100% |
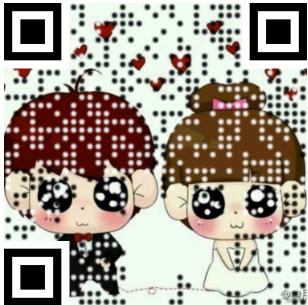
## 3.3 Comparison of Different Aesthetic QR Code Algorithms

To evaluate the performance of our algorithm, we compare our aesthetic QR code algorithm to those in [6] and [8]. The generated QR codes are presented in Table 5. The results of [6] are limited by the error

correction capacity, thus the salient region are almost covered by white and black points, and the visual effect is poor. The results of [8] are better, however, the salient region in left side of the image is damaged, the integrity of the image is damaged. Our algorithm avoids the deficiencies of the above algorithms, the salient region is shown completely, and the edge areas are preserved.

**Table 5.** The aesthetic QR codes generated by different algorithms

# 4  Conclusion

In this paper, a new algorithm for aesthetic QR code is proposed based on the salient region detection and SPBVM, which can display the salient region completely and is more flexible for the selection of background image. The salient region is not limited to the center of the image, and better visual quality can be obtained for the images with multiple salient regions.

In the algorithm, we make full use of the XOR characteristics of RS code, without sacrificing the error correction capacity of RS code. According to the acquired salient region, the basis vectors are selected from PBVM to form SPBVM. The associated RBVM can be conducted by carrying out the operation like Gauss Jordan elimination on SPBVM. The replacement in parity area with the RBVM generate the black and white modules which do not lie in the salient region. Experimental results show that the proposed aesthetic QR code algorithm can achieve a better visual effect.

## Acknowledgments

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