Multi-Style Migration QR Code

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Abstract. Quick Response (QR) code is a two-dimensional code that can be quickly recognized by a portable mobile device. It has played more and more important role in e-commerce, manufacturing, marketing and daily life. Therefore, the visual aesthetics of QR code is a significant performance that should be improved. Many proposed methods for beautifying QR code have good result. For the purpose of enhancing vision effect, simplifying complexity and improving robustness. In this paper, we propose a strategy which can be used to generate multi-style art QR code. Particularly, this strategy is capable of transferring more than one artistic styles to an art QR code. Aiming at visual smoothing, we adopt a method to generate the modified systematic encoding aesthetic QR code. In order to migrate multi-style, we improve a neural style migration network to suit the aesthetic QR code style migration tasks. Simultaneously, we propose an error-correction method to enhance the robustness of multi-style migration QR code which is generated by neural style migration network.

1. Introduction
Quick Response (QR) code has been one of the most widely used code. It is a type of two-dimensional code which contain black and white square modules. QR code provides a number of features, such as high capacity encoding of data, small printout size, dirt and damage, readable from any direction [1]. QR code has more capacity for information storage than conventional bar codes. Meanwhile, It has fast readability and can be read by smart phone rather than only read by barcode scanner. With the popularity of various sorts and varieties smart mobile devices, QR code beautification has been more and more useful.

QR code has strict shape and color restrictions. Therefore, the difficulty in beautifying QR code lies in how to express the art content under those restrictions. Figure 1 shows some of the beautiful QR code. Existing works have developed numerous algorithms [2]-[14], which can be roughly divided into two categories, approaches that substituting QR modules and approaches that modify image pixels.

The first class methods are based on replace QR modules by art image or logo. [3], [4] modifies several modules of an original QR code within a possible error correcting capability to display a small logo image [13]. By the method that exploiting unused modules in the padding regions [4], [8] maintain decoding robustness. QArt code designed using the method in [2] which manipulate the Reed Solomon encoding procedure to maximize the area coverage without undermining the corrective performance.

The second class methods are based on modifying the luminance or color of image pixels. One of the method [7] is chooses central pixels of each module which is the area usually sampled by the decoder to modify its luminance. This approach improves visual effects while maintaining robustness. However, it is very likely generate large quantities of the low pass artifacts because it is generally modifying a large proportion of the module area. Still others, [4] performance image by modifying the padding codewords, this method subjects to limitations on QR code encoding rules.
With the purpose of further improving visual effects and gaining strong robust art QR code. There are some other works using the above two types of methods at the same time. In [9], a method applied the half-toning technique was proposed with the goal of generating an aesthetic QR code. It split the QR modules into a set of pixels and preserve piece of pixels while using QR code to replace these central pixels. Zhang et al. [12] repositioned the module of QR code based on visual saliency and edge features extracted from background images. This method tends to allocate black/white modules in the visual focus area, and can output QR codes in visual-pleasure. There is a further work, Xu et al. [14] propose a novel type of aesthetic QR codes, SEE (StylizeAesthetic) QR Code, and a three-stage automatic approach to produce such robust art-style-oriented code. This method can output SEE QR Code which has a high quality in terms of both visual appearance and robustness.

![Figure 1. Existing art QR code.](image)

The difficulty with embedding method is that they should be decodable by standard applications. When adopted embedding method to change QR code, it will change the luminance of the code. As a result, the binarization thresholds could be distorting and the recognition accuracy could be greatly reduced. Another difficulty in embedding method is the selection of the number of replacement information modules. It subject to limitation, which depends on the correction capacity of the code. Embedding method must minimize the number of replacement modules while making the most of possible area to ensure the visual effect of QR code.

In this paper, we propose a strategy which can be used to generate multi-style art QR code. Particularly, this strategy is capable of transferring more than one artistic styles to an art QR code. Aiming at visual smoothing, we adopt a method to generate the modified systematic encoding aesthetic QR code. In order to migrate multi-style from more than one style images, we improve a neural style migration network to suit the aesthetic QR code multi-style migration tasks. Simultaneously, we propose a error-correction method to enhance the robustness of multi-style migration QR code which is generated by neural multi-style migration network.

This paper is organized as follows. Sections II reviews the structure and decoding procedures for QR codes. Concurrently, related methods of style transfer by neural network are briefly introduced. The proposed method to produce a multi-style migration QR code which have non robust is described in Sections III. Sections IV describe the error-correction method of enhance the robustness. Sections V demonstrate the results of our method and evaluate it.
2. Preliminaries

2.1. Structural of QR Codes
QR code has the advantages of large capacity, high reliability, strong anti-counterfeit and support a variety of graphic and text information. Besides this, QR code also has the following main features:

- 360 degrees fully read: better than row type two-dimensional code, such as PDF417 code.
- Extremely high reading speed.
- Extremely high reading speed.

Figure 2 is a typical QR code, which is a square array composed of square modules, mainly including two parts of functional graphics and coding areas. Functional graphics are mainly used to identify, locate, and restore rotational deformations, including position detection graphics, positioning graphics, separators, and correction graphics. The coding area is the data-encoded storage area, including format information, version information, data, and error correction codes.

There are a total of 40 versions of QR codes, each with a different size, the size of version 1 is 21×21 and version 2 is 25×25, and the size calculation method is \((4 \times j + 17) \times (4 \times j + 17)\). \(j\) is the version number, you can see that the bigger the version is, the bigger the size is, and it can represent more data. The structure of the QR code is composed of as follows:

- Finder patterns: A finder pattern is made up of three centers with overlapping, width ratio 3: 5: 7 and modules deep and shallow arranged square. A QR code contains three finder patterns, which are located on three corners of the two-dimensional code image. They can be used to identify QR code symbols and determine their direction and location.
- Alignment patterns: The Alignment pattern can be regarded as a small version of the finder pattern, and the width of its square is 1: 3: 5 from inside to outside. More than version 2 of the Alignment patterns are available, and the number of Alignment patterns increases with the increase of the version.
- Timing patterns: The timing patterns is a row and a column of graphics that are alternately composed of shallow and deep modules in the sixth column and the sixth row. The role of timing pattern is to assist positioning and determine the version and density.
- Encoding Region: The encoding region is the code area, which is delimited by finder patterns. It stores data, parity modules and decoding information. The version of the code decides the shapes of the codewords.

![Figure 2. Existing beautiful QR code.](image-url)
2.2. Decoding Procedures
QR code recognition is to read and preprocess QR code graphics through related image acquisition devices, and then decoding the original information of QR code. The recognition process of QR code is mainly divided into image preprocessing, location and correction, data reading, error correction and decoding.

QR code image can be divided into grayscale processing, smoothing processing and binarization. Scanning QR code with a camera, a color image is generally obtained, each pixel has three color RGB component values, component values range from 0 to 255. Since the traditional QR codes have only two colors of black and white, the RGB values do not contain useful information. Therefore, the color images must first be subjected to gradation processing [20]. Further, compared to a color image grayscale image, it will save more space and computation time. Binary images are generated by thresholding the gray scale image as:

\[
Q_b[i,j] = \begin{cases} 
1 & \text{if } Q[i,j] > t_{ij} \\
0 & \text{if } Q[i,j] \leq t_{ij} 
\end{cases}
\]  

(1)

Q is the QR code captured by the camera, \(t_{ij}\) is the threshold assigned to pixel \([i,j]\) and \(Q_b[i,j]\) is the binary result of pixel \([i,j]\) in Q. The most widely used libraries for QR code encoding and reading is the ZXing library [15]. In particular, the threshold \(t_{ij}\) is not constant, and ZXing uses the mean block binarization method to calculate the threshold \(t_{ij}\).

After preprocessing the QR code image, a grayscale pixel value is obtained. Next, the QR code is positioned and corrected, and then the data can be read. The QR code positioning is to find the pattern that matches the features of the finder patterns. The scanned image finds the portion that meets the proportion of the width of the finder pattern. As shown in Figure 3, This is a straight line passing through the finder pattern in the X-axis direction to satisfy the ratio of black and white widths. Adjacent pixels of the image, up to all the straight lines passing through the central module in the X direction are identified. In the same way, find all the straight lines passing through the center block in the Y-axis direction. Repeat the above steps to get the center position of the other two finder patterns.

The depicted QR code graphics usually have a certain degree of rotation on the angle, and need to be restored through image rotation. The rotation angle can be calculated from the coordinates of the center point of the finder pattern. At the same time, due to the shooting angle and other reasons, the scanned image is generally not a square, but changes in the geometric shape will occur, and become trapezoidal and other graphics. At this time, it is necessary to use plane projection conversion to restore the graphics. The planar projection transformation is the use of the perspective transform [16] planar projection conversion formula, using the vertices of the quadrilateral as the control point to convert the distortion quadrilateral in the original coordinates to the quadrilateral in the standard coordinates.
After position and correction, error correction and decoding are required. First, the corresponding values of the image are read, and the black and white image blocks are respectively identified as a matrix composed of “0” and “1”. Then read the format, version information, get the mask pattern and error correction level and QR code version. The XOR process is performed using the mask pattern and the QR code to obtain the original pattern before the mask. According to the rules of the layout module, the symbol characters are read, the data area of the original information and the error correction code are recovered, and the data is corrected by the error correction code. Finally, the original information is obtained by decoding according to the mode used.

2.3. Style Transfer
Most of the early style transfer methods were example-based [17] [18]. The image analogy method [13] determines the relationship between a set of images and applies it to other images to achieve style transitions. Because it is limited to finding dense correspondences, the analogy-based approach [18] usually requires a set of images that represent similar scenes. Therefore these methods are not suitable for arbitrary image style conversion tasks.

In recent years, image style migration based on neural network has always been a hot topic in artificial intelligence research. It is closely related to texture synthesis, and the images generated by these methods have the same style as the style target image as well as the semantic information of the target content image.

Neural network-based style transfer methods can be classified into two categories: One is based on optimization methods, for example, Gatys et al. [19]. The method of this paper is to directly modify the random noise so that the overall error is minimized. For each forward propagation of the method, the original noise is fine-tuned and gradually approaches the final effect map; The other is based on a feed-forward network, such as Ulyanov et al. [20], Johnson et al. [21]. These methods train the feedforward generator network for each specific style of target image, and replace the original time-consuming iterative optimization by forward transfer. In addition, The resulting networks are remarkably light-weight and can generate textures of quality comparable to Gatys et al., but more faster.

After that, many methods have been proposed to train a single network to migrate multiple styles. Chen et al. [22] propose a optimization objective based on local matching that combines the content structure and style textures in a single layer of the pre-training network. Liao et al. [23] proposes a two-image direct visual property migration method. This method is aimed at two images with different contents but similar semantics. For example, the bodies of two graphs are objects of the same category, and the semantic correspondence between the contents of the two graphs are established using high-level abstract features.

In this paper, we propose a strategy which can be used to generate multi-style art QR code. Particularly, this strategy is capable of transferring more than one artistic styles to an art QR code. In order to migrate multi-style, we improve a neural style migration network to suit the aesthetic QR code style migration tasks.

3. Multi-Style Migration QR Code Generation

3.1. Aesthetic QR code Generation Method
First, we generate a non-stylized artistic QR code $Q_a$ which roughly follow the framework proposed by [13]. The standard QR code uses the system code method of the RS code to generate an RS block. System coding indicates that the information symbol directly becomes part of the RS block. To generate a better RS block, it uses an encoding method that makes the binary string inserted into the QR code similar to the module pattern of the image and finds the best RS block in the candidate by exhaustive search. At the same time, in order to overcome the computational difficulties, a strategy called "random method" is used. This method randomly and uniformly selects candidates and checks the similarity to the module pattern. A plurality of candidates in the QR code, we select the best has a smallest number of pixel values to be displayed symbol image different modules.
After selecting the best RS block to replace, we adopt the methods [13] which proposed by M. Kuribayashi and M. Morii, to translate color. It is possible to use color for modules due to the QR code decoding algorithm. In the process of the camera device obtaining the QR code, the brightness of each module is calculated using a decoding algorithm, and the color space is converted into a luminance component. The approach to convert color is described as follows:

1. Change the scale of the input image, so that with a given version v QR code having the same size;
2. Convert the color components RGB to YUV color components, and obtain a luminance component \( Y_{i,j} \), \((1 \leq i, j \leq 17 + 4v)\);
3. Calculate the average \( \bar{Y} \) of the center squared value, which is a quarter of the size of the original image, where

\[
\bar{Y} = \frac{4}{L^2} \sum_{i=\frac{L}{4}}^{3L} \sum_{j=\frac{L}{4}}^{3L} Y_{i,j}
\]  

(2)

4. Determine the binary matrix \( B_{i,j} \), where

\[
B_{i,j} = \begin{cases} 
1 & \text{if } Y_{i,j} > \bar{Y} \\
0 & \text{otherwise}
\end{cases}
\]

(3)

The binary representation of the RS block placed on the QR code matrix is denoted as \( R_{i,j} \), \((1 \leq i, j \leq 17 + 4v)\). At the same time, \( R_{i,j} \) must conform to the black and white function mode at the corresponding position of the QR code. We eventually generate a QR code that relates to a given image, as shown below.

When \( R_{i,j} = 1 \),

\[
Y'_{i,j} = \begin{cases} 
Y_{i,j} & \text{if } Y_{i,j} > \bar{Y} + \epsilon \\
\frac{Y_{i,j}}{\bar{Y}} + \epsilon & \text{otherwise}
\end{cases}
\]

(4)

Otherwise,

\[
Y'_{i,j} = \begin{cases} 
Y_{i,j} & \text{if } Y_{i,j} < \bar{Y} - \epsilon \\
\frac{Y_{i,j}}{\bar{Y}} - \epsilon & \text{otherwise}
\end{cases}
\]

(5)

Where \( \epsilon \) is the threshold for ensuring the readability. The modified luminance components \( Y' \) and the original U and V components are translated to the RGB color component by this method. Finally, we obtain the non-stylized artistic QR code \( Q_a \).

3.2. Multi-Style Migration QR Code Generation Method

As shown in Figure 4, we roughly follow the framework proposed by [19]. The method uses neural representations to separate and recombine content and style of images, providing a neural algorithm for the creation of artistic images. However, their method is limited to a single image style migration. Therefore, we have improved a method for multi-style migration.

We input the content target image \( \vec{p} \) and the style target image \( \vec{a} \), and the output image \( \vec{x} \) should combine the semantic content of \( \vec{p} \) with the style features of \( \vec{a} \). The loss function we minimise is

\[
L_{\text{total}} (\vec{p}, \vec{a}, \vec{x}) = \alpha L_{\text{content}} (\vec{p}, \vec{x}) + \beta L_{\text{multi-style}} (\vec{a}, \vec{x})
\]

(6)
where $\alpha$ and $\beta$ are the weighting factors for content and multi-style reconstruction respectively. $L_{\text{content}}(\bar{p}, \bar{x})$ is the squared-error loss between the content image and output image feature representations, and the definition is as follows

$$L_{\text{content}}(\bar{p}, \bar{x}, l) = \frac{1}{2} \sum_{i,j}(F_{ij}^l - P_{ij}^l)^2$$

(7)

where $F_{ij}^l$ is the activation of the $i$th filter at position $j$ in layer $l$. $L_{\text{multi-style}}(\bar{a}, \bar{x})$ is the squared-error loss between the entries of the Gram matrix respective style representations from the original image and the Gram matrix of the image to be generated. The total definition of multi-style loss is as follows

$$L_{\text{multi-style}}(\bar{a}, \bar{x}) = \frac{1}{N} \sum_{n=0}^{N} \sum_{l=0}^{L} \omega_n E_{ij}$$

(8)

A layer with $N_l$ distinct filters has $N_l$ feature maps each of size, where $M_l$ is the height times the width of the feature map. The $n$th style image contribution of layer $l$ to the total multi-style loss is

$$E_i = \frac{1}{4N_l^2 M_l^2} \sum_{ij} (G_{ij}^l - A_{ij}^l)^2$$

(9)

Where $N$ is the number of style images, $\omega_i$ are weighting factors of the contribution of each layer to the total loss. $G_{ij}^l$ is the inner product between the vectorised feature map $i$ and $j$ in layer $l$.

In this paper, content image is the non-stylized artistic QR code $Q_a$, multi-style images are some of the art images we choose. We reconstruct style features from layers conv1_2, conv2_1, conv3_1, conv4_3 of the pretrained VGG-16, generating the multi-style migration QR code that mix the content of with the style of a paintings. However, the multi-style migration QR code $Q_n$ have non robust, we will propose a error-correction method of enhance the robustness in sections IV.

4. Error-Correction Method of Enhance the Robustness

We generated a multi-style migration QR code $Q_n$ in the previous stage, but there are many error modules in $Q_n$. Therefore, at this stage, we have designed an error correction method to generate robust results through non-stylized artistic QR code and multi-style migration QR code. The approach to enhance the robustness is described as follows:

1. Input the original picture $I_o$ that needs to be mixed with the QR code into the neural network, and input multiple style images we selected in the section III. Neural network will output multi-style migration image $I_s$;

2. Generate artistic QR code $I_a$ which is mixed with image $I_s$ by using the aesthetic QR code generation method;

3. Use the method which proposed in [24] to calculate the brightness value $L_a$ of the multi-style migration QR code $Q_n$. The formula for calculating the brightness is

$$L_a = \frac{1}{N} \exp\{\log[\delta + L(x, y)]\}$$

(10)

where $L(x, y)$ is the luminance for pixel$(x, y)$, $N$ is the total number of pixels in the image and $\delta$ is a small value to avoid the singularity that occurs if black pixels are present in the image. In this paper, we set $\delta = 0.0001$;

4. The $k$th encoding module of non-stylized artistic QR code $Q_a$ is $M_k$. We enhance the pixels of $M_k$ and generate enhanced encoding modules $M_k'$. The pixels of enhancing encoding modules is $Q_m'$, and the formula is
\[ Q_m' = \gamma_1 L_a + \gamma_2 \]  

In this paper we set \( \gamma_1 = -0.18 \), \( \gamma_2 = 19.98 \).

(5) Replace the modules of the artistic QR code \( I_a \) with enhanced encoding modules \( M_E \).

Through the above steps, a multi-style migration QR code which have robust will be generated.

5. Experiment

In this section we show the results of our algorithm processing. We have input a landscape photo and mixed it into the QR code. At the same time, we imported two style art images. Then we made a style migration for the original and mixed images and generated a multi-style migration QR code through the error correction algorithm. As is shown in Figure 5, (a) is the original picture \( I_o \) that needs to be mixed with the QR code, (b) (c) are the style images, (d) is the non-stylized artistic QR code \( Q_a \), (e) is the non robust multi-style migration QR code \( Q_R \), (f) is the multi-style migration QR code which have robust.

![Figure 4. Neural network structure of the multi-style migration.](image)

![Figure 5. Multi-style migration QR code generation process.](image)

Simultaneously, we use different mobile smart devices to test the multi-style migration QR code. These multi-style migration QR codes are displayed on SAMSUNE S22D300NY and the QR code recognition APP is Wechat. We test multi-style migration QR codes under different lighting conditions, and the success probabilities for some smart phones are enumerated in Table 1.
Table 1. Multi-style migration QR code readability test.

| Device            | Success probability [%] |
|-------------------|-------------------------|
| Iphone x          | 99.7                    |
| Iphone 6          | 98.3                    |
| Sony Xperia XZ1   | 88.6                    |
| MIUI8             | 75.4                    |
| ZTE Blade A2S     | 77.2                    |

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7. References
[1] QR code.com 2010 http://www.qrcode.com/en
[2] R. Cox 2012 Qart codes http://research.swtch.com/qart
[3] S. Ono, K. Morinaga and S. Nakayama 2008 Two-dimensional barcode decoration based on real-coded genetic algorithm Proc. CEC vol 8 pp 1068 – 1073
[4] T. Wakahara and N. Yamamoto 2011 Image processing of 2-dimensional barcode Proc. IEEE NBitS vol 11 pp 484-490
[5] Y.S. Lin, S.J. Luo and B.Y. Chen 2013 Artistic QR code embellishment Computer Graphics Forum vol 32 pp 137–146
[6] D. Samretwit and T. Wakahara 2011 Measurement of reading charactristics of multiplexed image in QR code Proc. INCoS vol 11 pp 552–557
[7] Visualead 2016 http://www.visualead.com
[8] M. Hagiwara 2013 Qrjam http://qrjam.jp/
[9] H. K. Chu, C. S. Chang, R. R. Lee and N. J. Mitra 2013 Halftone QR codes ACM Trans. Graph. vol 32 pp 1–8
[10] G. J. Garateguy, G. R. Arce, D. L. Lau and O. P. Villarreal 2014 QR images: optimized image embedding in QR codes IEEE Transac.Image Process. vol 23 pp 2842–2853
[11] A. Falcon 2013 40 gorgeous QR code artworks that rock http://www.hongkiat.com/blog/qr-code-artworks/
[12] Y. Zhang, S. Deng, Z. Liu and Y. Wang 2015 Aesthetic QR codes based on two-stage image blending International Conference on Multimedia Modeling vol 8936 pp 183–194
[13] M. Kuribayashi and M. Morii 2017 Aesthetic QR code based on modified systematic encoding function IEICE Trans. Info. and Sy. Vol E100.D, no. 1 pp 42–51
[14] Mingliang Xu, Hao Su, Yafei Li, Xi Li, Jing Liao, Jianwei Niu, Pei Lv and Bing Zhou Stylize Aesthetic QR Code arXiv 1803.01146
[15] O. S. Chen 2013 xzimg https://github.com/zxing/xzimg
[16] R. L. Bleyl 1976 Using photographs to map traffic accident scenes: a mathematical technique Journal of Safety Research vol 8 pp 59-64
[17] A. Hertzmann, C. E. Jacobs, N. Oliver, B. Curless and D. H. Salesin 2001 Image analogies Proc. SIGGRAPH vol 1 pp 327-340
[18] Y. Shih, S. Paris, F. Durand and W. T. Freeman 2013 Data-driven hallucination of different times of day from a single outdoor photo Proc. SIGGRAPH vol 32 pp 1-11
[19] L. A. Gatys, A. S. Ecker and M. Bethge 2016 Image style transferusing convolutional neural networks Computer Vision and Pattern Recognition
[20] D. Ulyanov, V. Lebedev, A. Vedaldi and V. Lempitsky 2016 Texture networks: Feed-forward synthesis of textures and stylized images arXiv 1603.03417
[21] J. Johnson, A. Alahi and F. F. Li 2016 Perceptual losses for real-time style transfer and super-resolution Proc. Eur. Conf. Comput. Vis. pp 694–711.
[22] T. Q. Chen and M. Schmidt 2016 Fast patch-based style transfer of arbitrary style arXiv 1612.04337
[23] J. Liao, Y. Yao, L. Yuan, G. Hua and S. B. Kang. 2017 Visual attribute transfer through deep image analogy Acm Trans. on Graphics vol 36 p 120
[24] Reinhard, Erik, Mike Stark, Peter Shirley and James Ferwerda 2002 Photographic tone reproduction for digital images ACM Transactions on Graphics vol 21 pp 267-276