Beautification of QR Code

Shreyas J
Student,M.Tech ,Computer Science
T. John Institute Of Technology
Bengaluru, India

Dr. Mahesh T R
Head Of The Department,Computer Science
T. John Institute Of Technology
Bengaluru,India

Ms. Roopashree S
Asst. Professor,Computer Science
T. John Institute Of Technology
Bengaluru,India

***Abstract*—Quick Response (QR) code is extensively used matrix bar code with the increasing population of smartphones. QR code usually consists of random textures which are not suitable for incorporating with other visual designs e.g. name card and business advertisement poster. Such short- comings of noise-like looks of QR codes are overcome by proposing a systematic QR code beautification framework where the visual appearance of QR code is composed of visually meaningful patterns selected by users, and more importantly, the correctness of message de-coding is kept intact. The proposed work makes QR code from machined-codable only (i.e. standardized random texture) to a personalized form with human visual pleasing appearance.**

Keywords—Aesthetic, mobile, QR code, Reed-Solomon codes, saliency, simulated annealing optimization.

I. INTRODUCTION

QR code is an matrix bar code containing much more amount of information than its 1D counterpart. It is an information container which can be captured and decoded by smart phones directly. The error correcting capability of OR code since Reed-Solomon (RS) codes have already been integrated into them. Tedious typing of users on the small screen of smart phones are avoided by QR codes. QR code were built based on various sizes in many applications [1]-[5].

QR code is the most widely been applied to numerous printed materials like posters, books or magazines. The cost of information transfer via QR code is extremely low as it is based on its visual appearance when compared with other technologies where specific hardware are always required.

When QR code is inserted into the host material like poster the noise-like appearance of QR code will disturb the visual design. The major challenge in decoding the QR code on the basis of appearance is producing the visual pleasant appearance and not affecting the accuracy of the decoded message. One of the common approaches [6], [7] enforced the QR design on embedding an icon directly. This approach introduces invalid code words in the resultant QR code, where the changeable area is bounded by the error correction capability, that is, the maximum area is usually less than 30% of the whole QR code area (which is determined by the max-imum error correction level of the QR code). In order to deal with this problem, an appearance-based QR code beautifier is

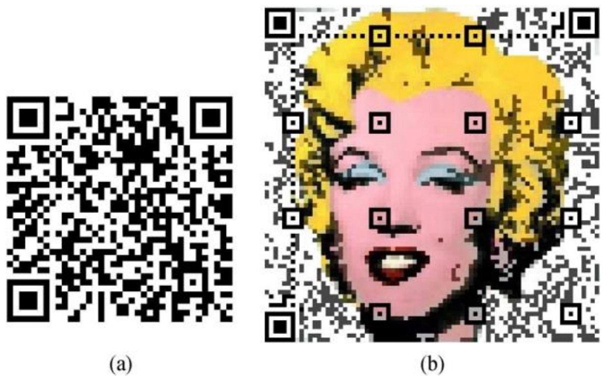

Fig. 1. (a) A normal binary QR code. (b) The beautified QR code produced by our approach. The embedded message is taken from 'http://ieeexplore.ieee.org'. Notice that (b) might be decoded a little bit slower because of the 'finder patterns' (pleasereferto Fig.2) are smaller than that of the normal QR codes

Proposed. This framework can embed visual pleasant images into QR codes without violating the specification for decoding. Several studies [6]–[11] addressed on the research topics of QR code beautification. The proposed method demonstrate a large changeable area in an asymptotic sense, as compared with existing approaches. Notice that the saliency regions of beautifying the embedded patterns are also taken into consideration during the QR code beautifying process, which generates more visual pleasant results. Fig.1 illustrates an example of applying proposed algorithm to embed the head image of Marilyn Monroe to a standard QR code.

II. BACKGROUDS OF QR CODE GENERATION

QR code is a two-dimensional bar code consisting of black and white square blocks where the smallest block (black or white) is defined as the module of a standard QR code. The code word of a QR code consists of 8 bits where one module represents the value of 1 bit (white for logical 0 and black for logical 1). The size of a QR code is determined by the ver-sion number V , $V < 40$, which corresponds to the size of $(17+4V)\times(17+4V)$ modules. The structure and the embedded error correction code of a standard QR code is briefed as following:

- Structure of QR code

The *finder patterns* are located at the three corners in Fig.2. The *finder pattern* is the most important pattern which enables the detection of the position of a QR code. Besides the *finder patterns*, there are *timing pattern*, *version information* and *format information* areas. For a QR code with version number, there will be *alignment patterns* for correcting the warping effect.

TABLE I

A LIST ABOUT THE NUMBERS OF DATA CODEWORDS AND ERROR CORRECTION CODEWORDS FOR DIFFERENT QR CODE CONFIGURATIONS WITH DIFFERENT ERROR TOLERANCE LEVELS

(Version, Correction Level)	Recovery Capacity (%)	Num. of data codewords	Num. of error correction codewords
$(15, L)$	7	523	132
$(15, M)$	15	415	240
$(15, Q)$	25	295	360
$(15, H)$	30	223	432
$(35, L)$	7	2306	570
$(35, M)$	15	1812	1064
$(35, Q)$	25	1286	1590
$(35, H)$	30	986	1890

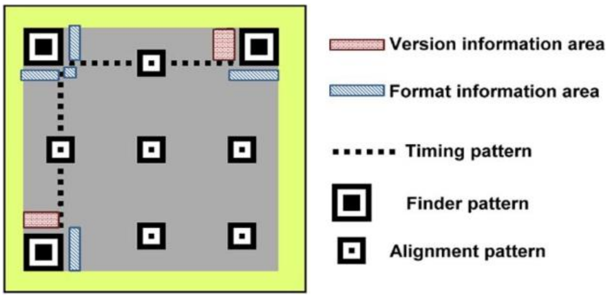

Fig. 2. The descriptions and locations of function patterns of a standard QR code.

The finder pattern, timing pattern and alignment pattern are called function patterns of a QR code. The other regions within the green color surrounded square are defined as encoding regions which can be used to store the information and the error correction code words.

- Error Correction

QR code utilizes RS codes for providing error correcting capability where the code words are represented by and appeared in consecutive modules. There are 4 error correction levels (i.e. L, M, Q and H from low to high) which can recover 7%, 15%, 25% and 30% error code words of the whole QR code. A QR code contains multiple RS codes, where one RS code is sufficient to store the message in general. The remaining RS codes are usually used to store non meaningful messages.

QR code with version number and correction level is denoted as (10, L). Table I shows a list about the numbers of data code words and error correction code words for different QR code configurations with different error tolerance levels. Since the target of QR code beautification is to find the valid code words for achieving visual pleasing appearance within the search space, Table I describes the difficulty of QR code beautification because of tremendous number of possible combinations.

A. *The Flow of QR Code Generation*

Fig. 3 illustrates the flow chart for generating a standard QR code, which includes the data analysis, the data encoding, the error correction encoding, and the placement and masking stages.

1) Data Analysis Stage: The information is analyzed in the data analysis stage which determines the error correction level and the encoding mode (e.g. numeric, alphanumeric). The suitable version and the capacity of QR code are decided in this stage.

2) Data Encoding Stage: At the data encoding stage, the embedding information is encoded into a bit stream according to the associated encoding mode, the terminator symbols (0000) is added to the end of the bit stream, and then the resultant bit stream is converted to 8-bit data code words. If the number of code words do not reach the capacity of the corresponding QR code, padding code words are added.

3) Error Correction Encoding Stage: In order to resist the noise during QR code acquisition, RS code is integrated into the standard QR code. RS code is utilized to detect and correct noise induced errors. RS code is very useful for correcting burst errors and is one kind of non-binary linear block codes, where denotes the length of the coding block and represents the length of message (i.e.the number of data code words). The length of parity code word is $n-k$ RS code can correct up to *t* error, where *t* is calculated as

$$t = \left\lfloor \frac{n-k}{2} \right\rfloor \quad (1)$$

and $\lfloor x \rfloor$ denotes the largest integer smaller than *x*. The values

of *n* and *k* are fixed in standard QR codes for a given version number and an error correction level. The errors are detected by checking the syndromes, denoted as $S(x)$, which are calculated by multiplying the parity-check matrix, H, with a given RS code word, $C(x)$, that is

$$S(x) = H(x).C(x) \quad (2)$$

The dimension of the parity check matrix *H* is $(n-k)\times n$, and $C(x)$ is an $n\times 1$ column vector. The verification process of legal RS code words can be represented as:

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$$\begin{bmatrix} 1 & 1 & \dots & 1 \\ \alpha^{n-1} & \alpha^{n-2} & \dots & 1 \\ \dots & \dots & \dots & \dots \\ (\alpha^{n-k-1})^{n-1} & (\alpha^{n-k-1})^{n-2} & \dots & 1 \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \dots \\ c_n \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ \dots \\ 0 \end{bmatrix}$$

where α is primitive root in a finite field F, and both α and F are specified in the QR code standard. Notice that both the addition and multiplication operations here are defined over the finite field F instead of the real field **R**.

4) *Placement and Masking Stage:* There are 3 kinds of code words (information, padding and parity) embedded in different regions of a QR code. Fig. 4 shows an example of the place- ments of a given message which consists of data code words (i.e. the information code words and the padding code words)

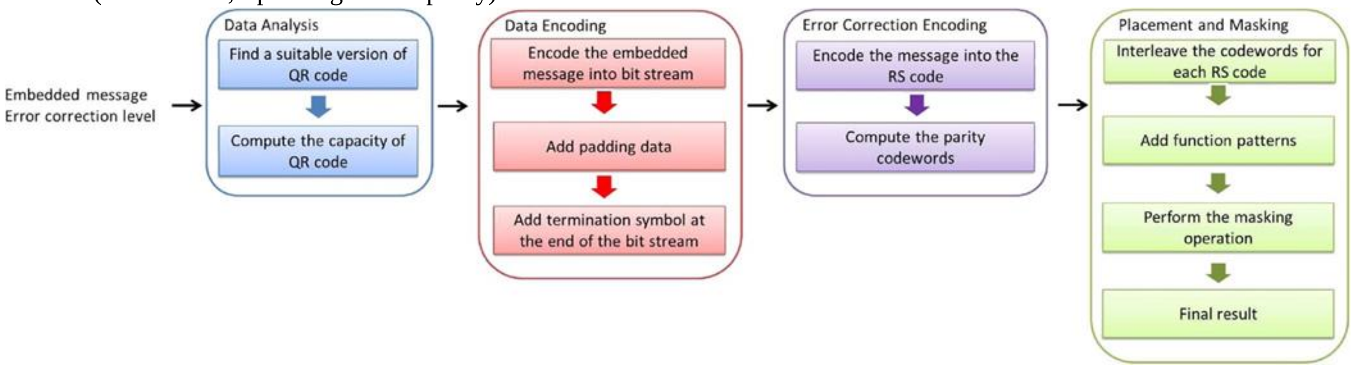
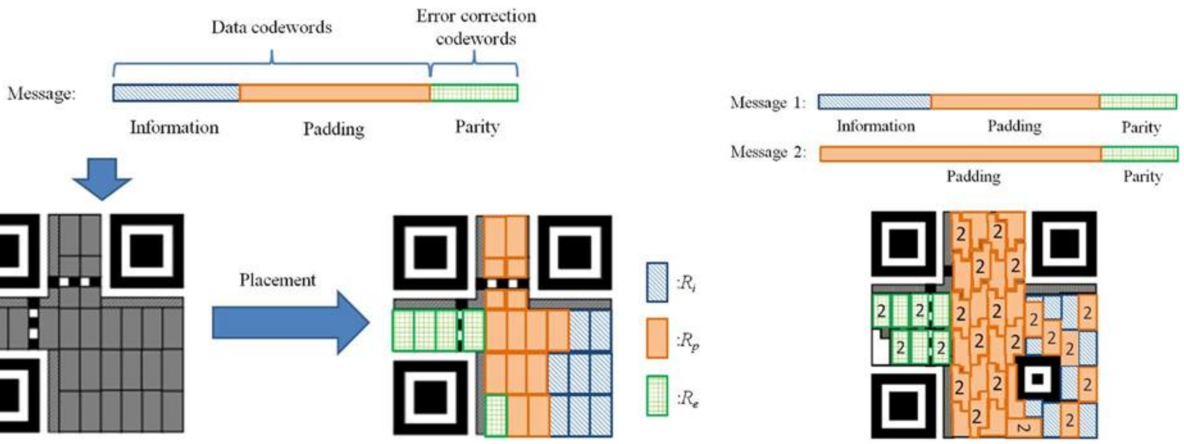


Fig. 3. The flow chart of a standard binary QR code generation.



(a) The placement of one message (b) The placement of two messages

R_i, R_p and R_e respectively.

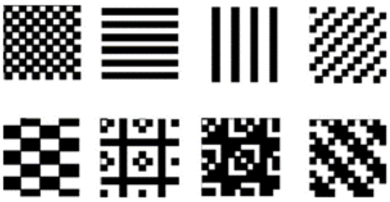


Fig. 5. The 8 mask patterns defined in the QR code standard.

The masking operation is utilized to eliminate the situations that the appearance of the encoded code words in the placement regions are identical to those of the function patterns. Fig. 5 shows the 8 mask patterns that are used in QR code generation [12]. The masking operation (i.e. XORing a chosen mask pat- tern) is the main reason for producing the noise-like appearance of QR code.

III. RELATED WORK

There are lots of studies [6]–[11], [13], [14] dealt with the QR code beautification by using different approaches. These research works can be classified into three categories: direct embedding, masking effect elimination in padding regions, and modifying the RS codes.

- Direct Embedding
  Brute force embedding [9]-[11] will introduce invalid code words in the generated QR codes. This approach has to incorporate the highest error correction level.
- Masking Effect Elimination in Padding Regions

The embedded message is separated from the padding data with specified termination symbols. The decoded message will not be affected by the values in the padding regions.

- RS Code Modification

The research works [8], [14] proposed modifying the RS codes to beautify the corresponding QR code which provides a more flexible approach as compared with the other beautification methods.

However, these studies did not take the saliency of the embedding image into consideration. The proposed system deals with the QR code beautification by seamlessly incorporating the saliency perception in to a global optimization process.

IV. THE PROPOSED METHOD

A standard QR code only defines the binary QR code. The issue of embedding color images into a QR code will be addressed. The incorporation of QR code beautification and simulated annealing will be demonstrated.

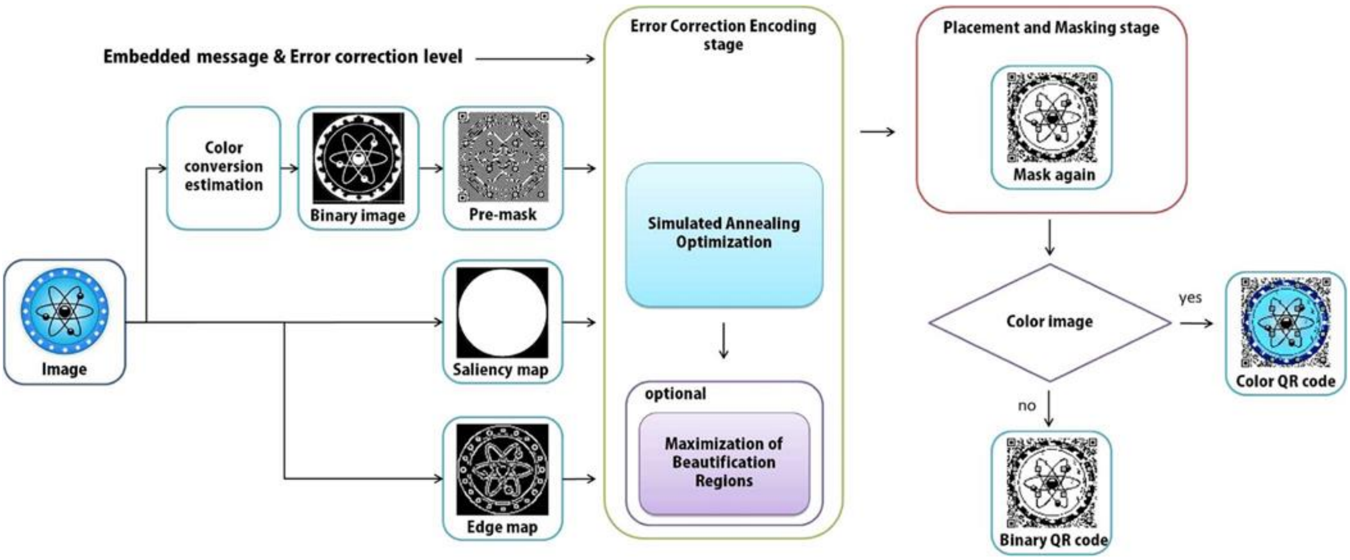


Fig. 6. The flow chart of the proposed QR code beautifier.

A. Saliency Consideration and Formulation

module m_j is equivalent to changing the value of one bit in an RS code- word (one code word is represented by 8 bits). The positions of the corresponding 8 modules of the *i*-th RS code word C_i are denoted as a data block B_i.

For an $[n,k]$-RS code without embedding message, let A_c denote the set of randomly selected k RS code words with assigned values from the image I and U_c represent the set of the remaining $(n-k)$ code words whose values are computed by substituting the assigned values of A_c into (3). The values of *n* and *k* are determined by the current QR code parameters (i.e. the version number and the error correction level). The target of QR code beautification is therefore equivalent to find an optimal A_c which minimizes the visual distortion.

The visual importance (or saliency) of a pixel p_j should therefore be taken into consideration for the selection of A_c. The saliency map S_I and edge map E_I of an image I are computed to assist the saliency consideration. The computation of saliency map S_I is conducted as: set $S_I(p_j)=1$(or 0) if the image pixel p_j belongs to the foreground (or background). The fore- ground/background separation is achieved based on the widely used segmentation tools. The edge map E_I is generated by using an edge detector, such as the widely used canny edge detector.

In order to minimize the visual saliency perception distortion in I_Q, the corresponding energy (or distortion) function can be defined as:

$$e(I,I_Q)=\lambda_1 D_h(I_{Q,}I)+\lambda_2 D_h(S_{1_Q,}S_1)+\lambda_3 D_h(E_{1_Q,}E_1) \quad (4)$$

where D_h represents the Hamming distance and $\lambda_{1\sim3}$ are the weighting coefficients.

Notice that I_Q is determined by the selection of A_c. As a result, the QR code beautification can therefore be formulated as an optimization problem, that is,

$$\min_{A_c} e(I, I_Q). \quad (5)$$

Since the space of A_c is in the order of $C^n_k = \frac{n!}{k!(n-k!)}$

Algorithm: Simulated annealing optimization

1: $A_C \leftarrow A^0_C$; $e \leftarrow e(I, I^0_Q)$
2: $u \leftarrow 0$
3: **while** $u < u_{max}$ **do**
4: $T \leftarrow (u_{max} - u / u_{max})$
5: $A_c^{next} \leftarrow$ Neighbor(A_C)
6: $e_{next} \leftarrow e(I, I_Q^{next})$
7: **if** $p(e, e_{next}, T) > R(0,1)$ **then**
8: $A_C \leftarrow A_c^{next}$; $e \leftarrow e_{next}$
9: **end if**
10: $u \leftarrow (u+1)$
11: **end while**

Algorithm 2 Swapping Algorithm

1: V_C is a queue with sorted code words in U_s by w_s descending order
2: for all $C_u \in V_c$ **do**
3: Randomly select a codeword $C_a \in A_c$
4: **If**($ws(C_u) / ws(C_a) + ws(C_u)) > r(01)$ **then**
5: $A_c \cup \{C_u\} \setminus \{C_a\}$
6: $U_c \cup \{C_a\} \setminus \{C_u\}$
7: end if
8: end for

B. Incorporation With Simulated Annealing Optimization

In order to deal with these challenges and achieve the goal of generating visual pleasant QR codes, simulated annealing (SA) optimization is chosen as our optimization mechanism, where the visual saliency consideration is also integrated seamlessly. SA optimization is a global optimization mech-anism which can achieve the global optimal solution with probability 1 with the expense of long execution time. In gen-eral usage, the global optimization will be early terminated when the results are good enough. SA optimization is chosen because we can easily integrate the saliency consideration during optimization.

Algorithm 1 shows the SA optimization adopted for beauti-fying the QR code. The components contained in Algorithm 1 are detailed in the following:

- r(0,1)

  The random number $r(01)$ represents a real number randomly selected from the range (01) with uniform distribution.

- Neighbor(A_c)

  We try to make the neighboring state $A_c^{neighbor}$ of A_c still contains the visual salient regions with high probability. The selection of $A_c^{neighbor}$ is based on the weight of RS codeword C_i, which can be computed by the Hamming weight of block B_i, that is

$$W_s(C_i)=1+W_h(S_i(B_i)), \quad (6)$$

where W_h denotes the Hamming weight and $S_I(B_i)$ rep-resents the block B_i in the saliency map S_I. Equation (6) implies that the weight of RS codeword C_i is pro-portional to the visual saliency of it, and the constant 1 is added to avoid the denominator becoming zero in the step 4 of Algorithm 2. The initial A_c^0 is generated by randomly choosing among the codewords with probabil-ities proportional to the associated image saliency (i.e. $S_I(B_i)$).
The codewords in $A_c^{neighbor}$ are generated by swapping the elements between A and U. The swapping algorithm is described in Algorithm 2.

P (e , e_{next} , T)

P (e , e_{next} , T) denotes the acceptance probability which is

C. QR Code Beautification With Color Image

The original standard QR code only defined in binary format, where the interpretation of image colors is done and depends on the QR decoder used. A QR code decoder will convert the color image into binary image before conducting the message decoding. We can reduce the noises induced from the conver-sion of color image to binary image by incorporating a better equipped decoder. However, the color conversion process may be different from decoder to decoder. Therefore, we take the color conversion of the open source QR decoder[4] as our reference.

D. Maximization of Beautification Regions

The changeable regions of a QR code are limited to the padding codeword region, R, and the parity codeword re-gions, R, in our work. We can further enlarge the changeable regions by incorporating with the direct embedding method. The data codeword regions can be directly modified as long as the induced error can be recovered. Fig. 7 demonstrates an example of beautification region enlargement where the visual quality of QR code is further improved, within the error correction capability. Table II compares the asymptotic sizes of changeable regions that can be achieved for different QR code beautification methods.

V. EXPERIMENTAL RESULTS

Fig. 8 shows part of the test data, where a (15, L)-QR code is used during the experiments and the direct embedding is not applied. We empirically set $\lambda_1=0.1$, $\lambda_2=0.9$ and $\lambda_3=0.4$ in (4) during QR code beautification. Both the subjective and the objective metrics will be applied to evaluate the performance of the proposed QR code beautification framework.

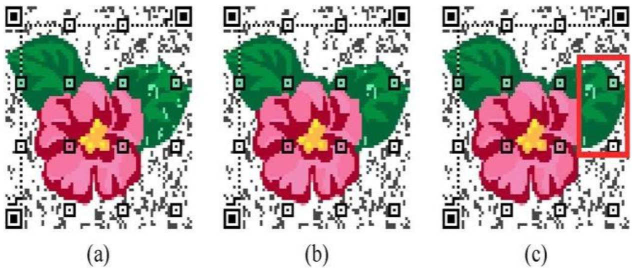


Fig. 7. (a) A beautified QR code without introducing any error codewords. (b) Visual noise reduction by introducing error codewords. (c) The marked square shows the visual difference between (a) and (b).

The research work [8] is the latest publication about QR code beautifica-tion which provides more flexibility and larger changeable area than those of previous works. It is our belief that the research work [8] is the state-of- the-art in the area of QR code beauti-fication. Therefore, it is realized and taken as our comparison target. There are 3 methods proposed in the research work [8] where only method 1 is compared in this work. This is because method 1 is the core basis of method 2 (user intervention is in-volved) and method 3 (fine-resolution version replacement is included). In other words, both method 2 and method 3 can be treated as the extensions of method 1; therefore, only the core algorithm, method 1 is chosen as the reference for comparison. Notice that, in the comparison, the same experimental assign-ments, such as setting the modules to be a visual pleasing image and restricting the system behavior follows (3), are assumed to both approaches. That is, only the selection procedures of the modules are different in the experiment.

A. Correctness of QR Code Decoding and Corresponding Performances

The correctness of decoded messages have been verified on several different mobile phones and QR code decoders, which are reported in Table III. The beautified QR codes with color image embedding will have slightly lower successful decoding rate as compared with their binary counterparts. The perfor-mance loss might come from the pre- described mismatch of color conversion among the decoders of different smart phones. Notice that the successful decoding rates are the same for both our method and the research work [8], since the decoding error is only introduced from the color mismatch between the actual QR decoders on the mobile phones and the reference QR decoder (i.e. Google ZXing) adopted in this work. Table III demonstrates decoding rates of both Binary and Color (15, L) and (15, H) QR codes, in which the embedded lengths are different (please refer

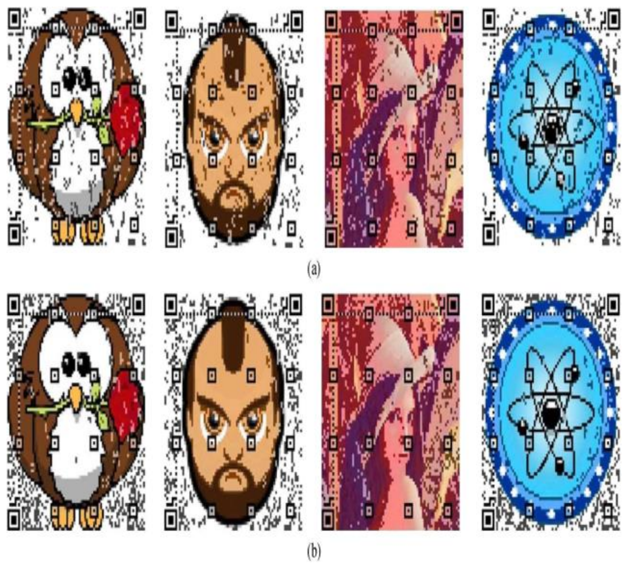


Fig. 8. Some examples of beautified QR codes. (a) The QR codes are generated by [8], and (b) the QR codes generated by our approach. The embedded message is ‘http://ieeexplore.ieee.org’, and a (15, L)-QR code is used.

to Table I for details). Notice that, even though the embedded message lengths are different, the successful decoding rates of (15, L) and (15, H) QR codes are the same. For QR codes with larger version sizes (say $V \geq 25$), the correctness of decoding will be reduced signifi cantly, because the corresponding mod-ules on a QR code are too small to be recognized correctly for
a normal mobile phone. This unstable decoding behavior also occurs in traditional QR codes without beautification, when the version size is too large.

B. Comparison of Time Complexity and Visual Quality

Fig. 9 demonstrates the comparison results of time com-plexity and that of visual quality between the proposed method and the research work [8]. Fig. 9(a) shows that the visual quality of the proposed method for the whole QR code is slightly lower than that of the study [8]. However, Fig. 9(b) demonstrates the visual quality of our method for the salient regions is almost 10 times better than that of [8]. Notice that, in these comparisons, the visual quality is measured by the Hamming distance $D_h(II)$ between the original image I and the designed QR code I . Fig. 10 illustrates the visual differences of the beautified QR codes and the corresponding noise distributions between our method and the research work.

Fig. 9 also shows that the visual quality (in terms of Ham-ming distance) is getting converged when the iteration number is greater than 600. The absolute execution time of the proposed method is about 10 second on a PC with MATLAB implemen-tation, when the iteration number equals to 600. The proposed method processes the codewords sequentially and iteratively where the maximum iteration number in our experiment is set to 1000.

C. Experiments on Various QR Code Configurations

To examine the impact of QR code configuration on the performance of QR code beautification, the required time complexity and the visual distortion of the proposed algorithm for various QR code configurations (i.e. different settings of QR code with different sizes of embedded messages) are investigated. We increase the size of the embedded message to 5% and 20% of the total information capacity of a given QR code version, and evaluate the visual distortion (in terms of Hamming distance) on

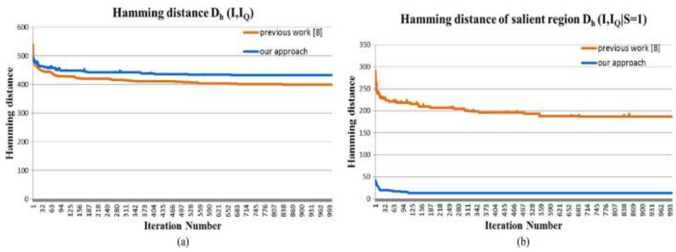


Fig. 9. The comparison of time complexity and the visual quality between the proposed method and the research work [8]. X-axis represents the averaged number of iterations among the test data and Y-axis shows the Hamming distance between I and I. The visual distortion $D_h II$ is expressed based on (a) the whole QR code and (b) the salient regions $(S_I=1)$ of image I.

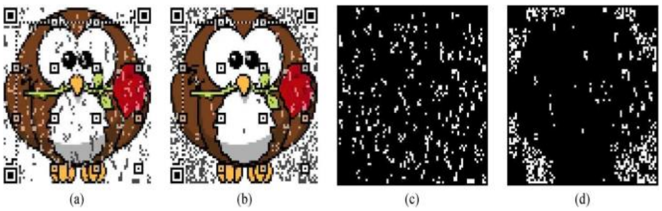
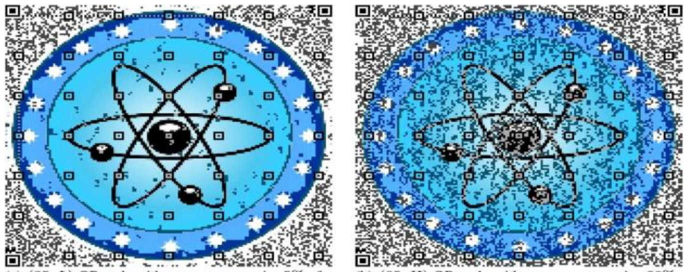


Fig. 10. (a) The beautified QR code generated by [8]. (b) The beautified QR code generated by our approach. (c) The noise distribution of (a). (d) The noise distribution of (b).

the salient and the whole regions for each one of the QR codes (from (15, L) to (35, H)), listed in Table IV.

Table IV demonstrates the required time complexity and the corresponding visual distortion for various QR code configu-rations. In fact, the required time complexity of the proposed approach is about $O(VV_2)$, where V is the size (version size)
maximum iteration number is set to 1000 initially, we examine the convergence of each codeword based on the corresponding Hamming distance, and the codeword with converged result (i.e., the corresponding Hamming distance is less than a given threshold or the distance remains the same for a few itera-tions successively) will be skipped during the computation. The
numbers of early converged codewords are also listed in Table IV. Notice that the QR codes with higher error correction levels or larger embedded message lengths will have more number of early converged codewords. The visual quality (in terms of Hamming distance) of a QR codes embedded with a large-sized message is difficult to be improved, the



(a) (35, L)-QR code with messages occupies 5% of the total capacity
(b) (35, H)-QR code with messages occupies 20% of the total capacity

Fig. 11. The distortions in the salient regions of the above two enlarged and beautified QR code examples are (a) 0.33% and (b) 29.91%, respectively. Notice that these QR codes may take a longer time for decoding (or not decodable) due to their large version sizes.

corresponding visual quality will easily reach to a fixed state, and therefore, early terminate the optimization process. Of course, QR codes embedded with short URLs will converge quickly, since almost all the area of QR codes are changeable and can be assigned with the visual pleasing images at early stages of optimization. The time complexity and the visual distortion reported in Table IV can be used as references for users to select proper configurations of the proposed QR code beautification schemes. We also compare the visual appearance results between the previous work [8] and our method when the embedded message size is enlarged (i.e. 20% of the total capacity) and the results are illustrated in Table V. As compared with the previous work [8], the proposed method improves the visual appearance significantly in the salient regions with the expense of little increased distortion in the whole region even if the embedded message size is enlarged.

D. Subjective Evaluation

We invited 20 participants (12 males and 8 females) with ages, ranging from 23 to 55 who are not engaged in this work. We ask the participants rating about the attractiveness, clearness
the annoyance level of noise, and the visual similarity between I and I . The scores are ranged from 1 to 7 points to express the level of opinions. The subjective evaluation results, presented in Fig. 12, show that the proposed method performs statistically significant $(p<0.05)$ better than [8] in all aspects. This result reflects that the proposed method does successfully address the issues of visual saliency perception

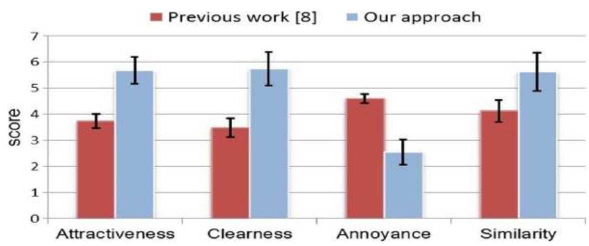


Fig. 12. The comparison of user study between the work [8] and our approach. The user study shows that our approach is statistical significantly $(p=0.007 \ll 0.05)$ better in all aspects.

VI. DISCUSSION

The color image beautification will be affected by two major factors: the resolution of QR code and the color conversion. Since one module (i.e. the smallest block) in a QR code corresponds to one pixel of a color image, the available resolution of QR code is quite limited; therefore, the color image embedded in a QR code should be resized to fit the resolution of the cor-responding QR code. Of course, we can increase the version of QR code to obtain higher resolution for better color image rep-resentation, but the increased version of QR code will impose a burden on QR code decoder, which may result in a longer de-coding time or even un-decodable fault. In our experiences, a normal QR code decoder may not capable of decoding the QR codes with version size larger than 20. Of course, the decoding ability depends on the capability of equipped QR code decoder on the mobile phone.

SA optimization framework is adopted in this work because the saliency considerations can be seamlessly integrated into the choice of neighboring states (c.f. (6)). Since SA optimiza-tion has an explicit state transition behavior as compared with other optimization methods (e.g. Neural Networks), we can inte-grate the saliency consideration into the state transition behavior easily. We do believe that SA optimization is just one of the pos-sible solutions to accomplish the required beautification task. The ease of implementation and the ability to achieve seamless integration makes SA on the top of the candidate list. Actually, as long as the saliency considerations can be successfully in-corporated into the optimization procedure, other optimization approaches, such as Genetic Algorithm and Neural Networks, may also be utilized in the proposed framework.

VII. CONCLUSION

In this paper, we present a systematic framework for QR code beautification. We integrate the visual saliency consideration seamlessly with simulated annealing optimization. The beautified QR code is evaluated by both subjective and objective metrics which all show the superiority of the proposed method. Since QR code has already been ubiquitously utilized in this mobile computing era, the beautification of QR code is a problem with high impact. This work can greatly enhance the aesthetic perception of QR codes for users. We expect this work can extend the usage of QR codes in various mobile multimedia applications.

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