Aesthetic QR: Approaches for Beautified, Fast Decoding, and Secured QR Codes

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Abstract: A QR code is a two-dimensional code that encodes data but it is unattractive and not ideal. QR codes have been applied in item identifications, publicity campaigns, advertisements, product promotions, etc. so they need to be visually good in appearance. Visually good and decorated QR codes degrade the decoding rate as compared to the standard QR code decoding rate. As they are used for mobile payments and logins some security must be there. For this many researchers have contributed using various approaches to beautify QR codes with high decoding accuracy and to make them secure. This paper aims towards the study of works carried out in the direction of beautification of QR codes using blended type techniques and artificial intelligence based techniques by different authors. The present state of prior strategies, methods, and major features used are described in this survey.

Index Terms: QR code, aesthetic QR code, beautification, decoding rate, security.

1. Introduction

QR codes are square-shaped black and white in color which can be read with smartphones, handy scanners, handy terminals, and fixed scanners. The QR code can encode data, URL links, coupons, details of events, product landing pages, etc. that users wanted to convey. QR codes have a high data capacity of up to 7089 characters. QR codes are dirt and damage resistant and can be readable from any direction in 360˚. Multiple QR codes can be combined into a single QR code.

QR codes have been applied in publicity campaigns, advertisements, product promotions, item identification, etc but the randomized black and white patterns make them unattractive. Multiple applications [1-5] and due to the widespread use of QR codes in the industry, there is a need for beautification of QR codes. Beautification of QR codes is to embed an image or a poster on the original QR code to make them visually better.

Several studies on the topics of the QR Code beautification research are discussed [6-11]. QR code beautifying is done in a variety of ways, which can be divided into three categories: manual embedding, embedding type, and blended type approaches. Manual methods are expensive and inefficient because they are not automated, time-consuming, and have a poor decoding rate. Embedding type [9-11] enforces logos, icons, images, URL, etc. on the central part of the QR code keeping in mind that the covered region can be recovered by the error correction capability of the RS code. The appearance of these types is not so good and even they don't maximize the changeable regions. Module based modifications are done in the codewords of QR code to adjust the image to be displayed. Pixel based modifications are done to modify the pixels of the image to be embedded. Both module-based and pixel-based adjustments are performed using blended type approaches to improve the visual quality of QR codes.

The major challenge in beautifying QR codes is maintaining that the original data is not modified and that the code can be scanned successfully by standard scanners. Visually good and decorated QR codes degrade the decoding rate compared to the standard QR code decoding rate. The second difficulty is utilizing the entire region of the code in which the picture is to be inserted. The number of modules that may be replaced depends on the code's correction capability, this cannot be accomplished by only restoring information modules with the image. The third challenge is to improve the security of QR codes during scanning. Without violating the encoding conditions, there is a requirement for a method that would inject aesthetic visual images into the QR codes.

The aim of this paper is to provide researchers with a survey of existing QR code beautification techniques and data hiding techniques to make them secure. In Section 2, we discuss the basics of QR code to have better

understanding of its encoding and decoding process. Next in Section 3, existing studies on QR code beautification and research related to security in QR codes are reviewed. Section IV concludes this work along with the future scope.

2. QR Code Basics

QR code consists of black and white squares where the smallest either black or white square is called a module. Every module is of 1 bit, a white module represents a 0 whereas a black module represents 1. The smallest QR codes are 21×21 pixels, and the largest is 177×177. The minimum specification of QR code is version 1 having 21×21 pixels and the maximum version number is 40 having 177×177 pixels and each version differs by 4 pixels. QR code uses RS codes for providing error correction. Table 1 depicts various error correction levels along with their correction capabilities.

Table 1. Error correction levels and correction capability

Error Correction Levels	Correction Capabilities
Low (L)	7%
Medium (M)	15%
Quartile (Q)	25%
High (H)	30%

2.1 Structural details of QR code

The QR code is represented by (V, E), where V denotes version information that is being used and E is the error-correcting capability used. Fig.1. shows the basic structure of the QR code. QR code comprises functional patterns and coding regions. The four functional patterns are finder patterns, timing patterns, alignment patterns and separators. Patterns of function are the shapes that should be placed in specified areas so that QR code scanners can accurately recognize these patterns to decode them correctly.
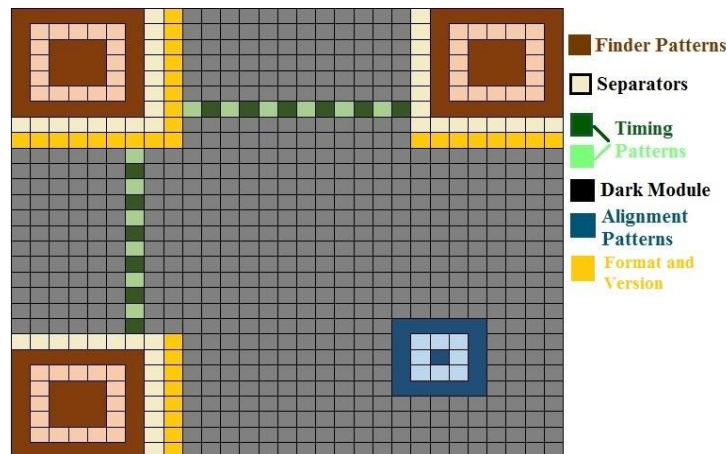

Fig.1. Structure of QR code

- *Finder Patterns:* Finder patterns are exceptional position identification patterns that are located in the corners of the structure.
- *Separators:* Separators are one module wide space of white color besides finder patterns.
- *Timing Patterns:* They are vertical and horizontal timing patterns that connect finder patterns. They are alternate black and white modules used to define module direction.
- *Alignment Patterns:* Alignment patterns are identical to finder patterns but are smaller in size. They are used in version 2 or higher versions to locate and orient QR codes while scanning. The number of alignment patterns in QR codes depends on versions.

- *Coding Regions:* Coding region contains the actual data to be encoded along with padding bits, parity bits, and error-correcting codewords. The encoded message is placed in the coding region according to certain patterns which are defined in ISO standards of QR code.
- *Dark module:* Dark module is a single black module besides the bottom left of the finder pattern.

2.2 Encoding

The flow chart of encoding is shown in Fig.2. The QR code can be encoded using the numeric, alphanumeric mode, byte, and Kanji. Data analysis is performed to select the most ideal mode based on message length and error correction level. Every mode uses a different method to convert text into strings. In data encoding, mode indicator and character count indicator are added to the string of bits. After encoding, data error correction codewords are added using Reed Solomon (RS) code. The bits are placed in the QR code framework in a specified manner during structuring the final message. Eight mask designs are defined in QR code specification and one of them is XORed with modules for data masking based on penalty rules. Lastly, information about format and version is added to the QR code.
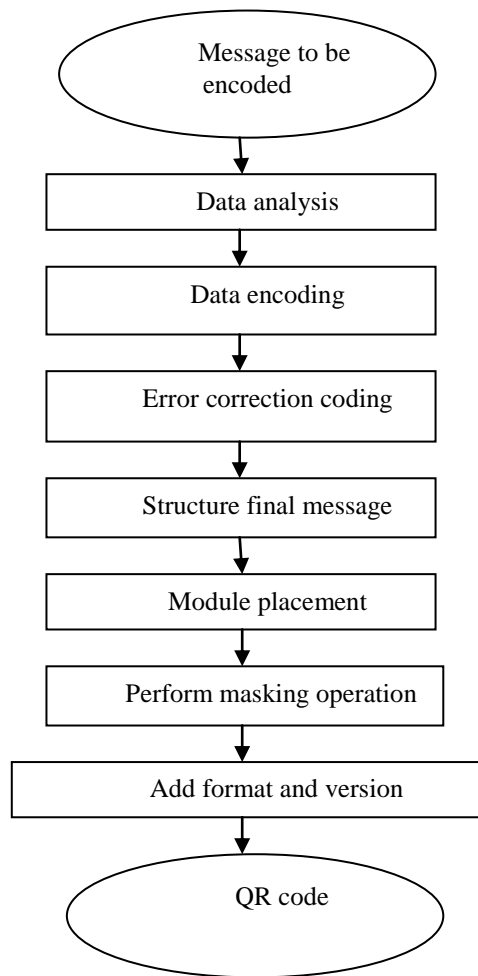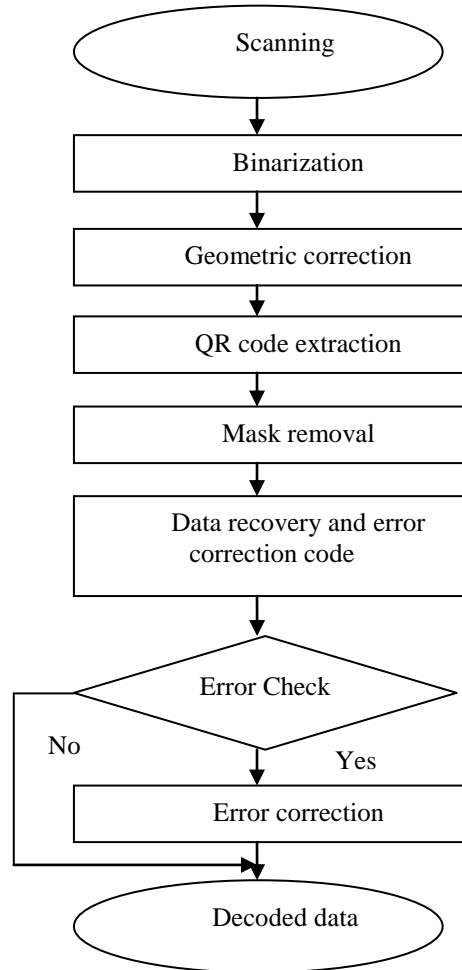
Fig.2. Flow chart of encoding

Fig.3. Flow chart of decoding

2.3 Decoding

Fig.3. specifies the basic steps of the decoding process. QR code extraction starts with the location of the finder and alignment patterns followed by extraction of version information using some sampling.

3. Study of Existing Literature

This section provides the details of recent works that have been carried out in the field of QR code beautification and the field of QR code security.

3.1 QR Codes Beautification

QR code beautification is done using different methods and can be broadly categorized as Direct Superimposition, Blended type techniques, and Artificial Intelligence-based techniques.

3.1.1 Direct Superimposition

Images of small size or generally logos are directly superimposed on QR codes. Research works in [11] preferred to use the center of QR code for image embedding. Invalid codewords get introduced and affect the decoding rate and data information gets distorted. Studies in [9-11] have used direct superimposition. Visual effects in direct embedding are not ideal. The changeable area cannot be extended in these types of beautification techniques.

3.1.2 Blended type techniques

Both module-based modification and pixel-based modifications are done in blended type techniques to improve visual quality. Pixel-based modification modifies the image to be embedded using different image processing techniques. Module-based modification alters the shape, color, and size of the module. Editing in the padding region of QR code and modification in RS code is module-based solutions. RS code is systematic code and the XOR property of RS codes is used as a principle to modify modules. Studies on blended type techniques are as follows.

A different approach to the creation of scanning-robust QR codes is suggested in [12], focusing on a module-based probability scanning system that successfully copes with the compromise between aesthetic appearance and scanning robustness. By measuring the chance of effective sampling, this method adjusts the luminosity of each module locally. To increase the visual accuracy of aesthetic QR codes, this scheme employs a gross to the finer hierarchical technique that generates codes sequentially: a binary aesthetic QR code, a grey aesthetic QR code, and an aesthetic colored QR code. By changing these initialization parameters, the proposed work can even be utilized to generate QR codes for various visual forms. User polls and encoding experiments were used in combination with existing algorithms to analyze the proposed method, indicating that the proposed methodology was outstanding in terms of both visual consistency and scan success rate.

A novel algorithm is suggested in [13], which focuses on identifying salient regions and selectable positive base vector matrixes (SPBVM). Next, to determine the saliency values of the image depending upon existing salient field detection algorithms, the sensitivity of the texture features is extended. The substantial area of the picture for the subsequent beautification phase is retained according to the salience diagram. Reasonable base vectors can be chosen using the proposed SPBVM in accordance with the output region obtained and the output field is completely displayed using the original QR code and the selected base vector XOR method. Finally, it combines the context image with the original QR file to achieve an aesthetic QR code. The above-proposed algorithm shows more stable and user-friendly visual effects at similar locations.

The study [14] establishes a structured basis for the embellishment of the QR codes. The suggested analysis seamlessly integrates the concern for visual salience with simulated annealing optimization. Both subjective and quantitative tests assess the embellished QR code, both suggesting the superiority of the proposed solution. In this age of mobile computing, provided that QR code has already been used everywhere, embellishing QR code is a high-impact task. This research strengthens the aesthetic comprehension of QR codes among consumers.

Analysis in [15] demonstrates a two-stage method utilizing QR codes to produce high-quality visual content. The basic QR code with a safe decodable rate but low visual clarity is synthesized first based on the Gauss-Jordan removal process. The rendering algorithm is designed in the second level to maximize graphic precision while avoiding the QR code decodable rate. The experimental findings indicate that the approach suggested significantly enhances QR code appearance and that processing difficulty is almost real-time.

The study [16] takes into account the features of the images to be viewed in the QR code and proposes an approach for producing a visually enhanced QR code without compromising its potential to rectify errors. The proposed research often explores the type of modules representing the object to be addressed and takes care of the trade-off between the optical presentation and its readability.

A study in [17] suggests an aesthetic QR code generation technique that utilizes QR code encoding rules of the Reed-Solomon error correction system. First, the proposed work marks the position of the codewords as the layout of the codewords according to the features of the QR code. The illuminated areas of the background image are defined in order to create the salience diagram. In order to determine the saliency values and filter and choose the right codewords as the fields you may change, the next stage is to add the codeword to the saliency map. Finally, recommendations for the removal of the hierarchical module are recommended. The redundancy potential of the RS error correction is the theoretical maximum value of the regions to be modified. The suggested algorithm would optimize changeable areas compared to current methods and highlight significant background image regions. This algorithm, while retaining the rate of efficient encoding, has better graphical performance.

The study [18] introduces a new interactive approach for the creation of an aesthetic QR code. Dynamic user strokes are used in the suggested solution as hints to eliminate redundant portions of modules that depend on the assistance of the error correction system and the background color thresholds by providing encoding details and decorating the image as a full QR code background. This approach is found to be compatible with the intent of the QR code creator compared to previous approaches so that it can generate more user-friendly results for the customer while ensuring the high readability of the machine.

The research in [19] demonstrates a way to incorporate a color image that minimizes the noise-like appearance of a code utilizing circular modules. The luminance of the signal pixels corresponding to the center and neighboring regions of the circular message module is balanced in such a way that they are coupled with the least interference of the optical code and the resulting information displays a strong degree of robustness in decoding. In order to test the visual attractiveness and noise and blur tolerance of the resultant codes, the results of the experiments demonstrate that visually appealing codes have a decoding rate similar to the original QR codes, which motivates an attempt to incorporate an image that is not otherwise attractive in the QR document. The comparison of suggested code three other recent methods is done for visual appearance and decoding robustness. The findings of this study reveal that, among the codes suggested by other new approaches, the codes given by the proposed system have the highest visual appeal. They are the greatest of codes with equal visual appeal and the second-highest of all codes in terms of resistance to noise and blur.

A combined approach for beautification and capacity improvement using modulation of the edited modules with the second level message and the background image is proposed by [20]. Firstly, the modified module is modulated with a binarized module-based background image. Textured patterns are drafted to improve the storage capacity of

modules. And then modules of basic QR codes are modulated in the L channel of the background image. Finally, optimization of module elimination parameters is done to enhance visual appearance and reduce decoding error. The research results prove that the said algorithm is better than other compared methods to improve visual quality and capacity.

3.1.3 Artificial Intelligence-based techniques

Most of the studies based on Artificial Intelligence use Neural Style Transfer (NST) approaches with Convolutional Neural Networks (CNN). The use of CNN-based techniques improves decoding speed and recognition rate. Parametric and non-parametric texture synthesis is done in NST. Optimization-based style transfer produces enhanced images but is a time-consuming method. Feed-forward networks results in nearly real-time. Research studies related to this is as follows:

In order to create personalized, diverse, attractive, and durable stylized QR codes, the research incorporates the Neural Style Transfer technique and proposes a new framework named ArtCoder. [21] proposed a sampling-simulation layer, a module-based code loss, and a competition mechanism to ensure that the stylized QR codes produced are robust while scanning. The experimental findings demonstrate that the proposed stylized QR codes are of acceptable consistency and capable of being deployed in the real world.

Research in [22] suggests an aesthetic QR codes, a QR Stylized Aesthetic (SEE) code, and a three-stage processing mechanism for such stylistic, robust code processing. This research shows a way to construct a simple, aesthetically tailored QR code that eliminates visual contrasts between the mixed image and the black-and-white noise-like modules. For the second level, the proposed solution adapts an acceptable neural-style transformation network to include decorative elements for a simple aesthetic QR code to achieve an art-style QR code. The study suggested the development of a robust, flexible, 3rd-level optimization strategy to ensure consistent efficiency by juggling two conflicting conditions: visual integrity and readability. Extensive tests have shown that both the graphical presentation and the power of the SEE QR codes are accurate and provide consumers with a wider range of personalized options.

Arbitrary style transfer of facial images is proposed in [23] for an aesthetic QR code. Feedforward network is utilized for better optimization. The stylized image and the content image are unified in some layer of CNN. The experimental finding guarantees both decoding rate and visual effect when their method is used in pre-processing. Visual model and semantic segmentation are combined to form the network. The decoding rate and visual effects are improved when the proposed approach is used for pre-processing the background. Their work is limited by color distribution and uniformity for small areas of the facial image.

3.2 QR Codes Security

Numerous studies [24-28] dealt with the security of beautified QR codes. Because of advancements in technology, QR codes are prone to attacks. Some researchers have added watermark in aesthetic QR codes, some have used different cryptographic schemes and some have used key and lock mechanisms. Research in [24] proposed an access control system using aesthetic QR codes using key and lock mechanism by appending user's photo on QR code. To improve communication security [25] have used a virtual secret sharing scheme for authentication based on QR code (VSSAQR). Results proved their scheme prevents various malicious attacks.

A novel distributed color QR code is proposed in [26] compatible with a standard QR code decoder. They have embedded the secrets in red, green, and blue channels of the colored image using threshold parameters. The contrast of shallow and deep modules of color QR code is necessary to maintain for correct decoding of QR code after binarization. The experimental result shows that the proposed scheme can be decoded by standard decoders with faster decoding speed and can sustain some types of noise. Within the threshold range, they have high secret storage capacity.

Research in [27] incorporates the embellished QR code with the data hiding algorithm. Depending on the error-correcting process, the QR code beautification algorithm is used to produce the aesthetic QR code. The modules are replaced with the error-correcting features enabled during the development process of the aesthetic QR code. The tested QR code is combined with the aesthetic QR code to avoid it from being corrupted. This enhances the security of QR code when it is controlled by the user. The original picture enclosed` by QR code and tested QR code are incorporated into the embellished QR code utilizing the LSB data hiding technique. The findings indicate that, in terms of visual quality and protection, the embellished QR code created by the suggested algorithm is of higher quality than the reference method.

A novel authentication algorithm based on a positive basis vector matrix and directed texture pattern for aesthetic QR code is proposed [28]. As QR code stores important data, therefore they need to be secured. For that watermark is encoded into a 4-bit gray code. Firstly aesthetic QR code is generated using fusion strategy of preprocessed image and QR code constructed with PBVM. Then watermark is embedded into QR codes blocks. DPTM is cut and rotated by angles to get an authentic aesthetic QR code. Experimental results prove that watermarks can be extracted properly and QR codes can be decoded correctly. Methods realized security authentication and visual quality. It also improved watermark capacity and robustness.

Summary of works carried out by various researchers shown in Table 2.

Table 2. Summary of observations

S.No.	Authors	Year	Purpose	Techniques / Methods used
1	Karelia Pena-Pena et al. [29]	2019	Visually pleasant QR Code, Decoding Robustness	Channel coding optimization.
2	LIN et al. [14]	2013	QR Code beautification framework	Visual saliency consideration and Simulated Annealing Optimization.
3	M.Xu et al. [22]	2017	Robust, Artistic, Personalized QR code	Neural style transformation, module based robust optimization mechanism.
4	A. Mittal [19]	2017	Visually Appealing QR code	Luminance modification algorithm. Algorithm uses circular modules of variable radius to differently modify luminance of image pixels.
5	Shih-Syun Lin et al. [15]	2015	High quality visual content	QR Code synthesis using Gauss Jordan Elimination procedure (GJEP). Rendering process for visual quality improvisation.
6	M. Kuribayashi et al. [16]	2016	Visually better aesthetic code, resolution improvement.	Based on generic properties of images proposed weighing functions to adjust symbols of RS Code. Proposed some module types for resolution improvement.
7	Hui-Li Cai et al. [20]	2019	Beautifed QR Code, Improved storage capacity	Based on Sequential Module Modulation. Designing of low pass textured patterns
8	Li Li et al. [17]	2015	Better aesthetic effects with better decoding rate	Saliency Detection is used. Module modification based on saliency region. Hierarchical module Replacement for unchangeable regions.
9	Jong-Kai Lee et al. [30]	2020	Improved Recognition Rate, Visually pleasing, hidden information	Convolutional Neural Network to reduce noise due to halftone and to improve recognition rate.
10	S. J. Liu et al. [31]	2017	Secured, Visually improved QR Code	Sub-division of modules based method to optimize visual effect. Digital Signature and watermarking based authentication scheme
11	L. Li et al. [28]	2020	Aesthetic QR Code, Security Improvement.	PBVM based aesthetic code is combined with watermark using directional periodic texture pattern
12	H. Cai et al. [27]	2020	Beautification and security enhancement during scanning	Optimization based on modification on function patterns and removal of some modules. Least Significant Bit (LSB) data hiding method.
13	Hao Su et al. [21]	2020	Scanning Robustness and visual effect improvement	Neural style transfer. Proposed Sampling Simulation layer and introduces module-base code loss for robust scanning.
14	P.C Huang et al. [24]	2017	Beautified QR code with secured key -lock mechanism	Symmetric key cryptographic algorithm. Synthesis mechanism from user's photo and aesthetic code is proposed.
15	S. Zhang et al. [23]	2020	Guarantees visual effects and decoding rate	Arbitrary style transfer. Semantic segmentation.
16	L. Li et al. [13]	2018	Aesthetic QR code	Salient region detection and SPBVM.
17	Z. Fu et al. [26]	2020	Ensures security, Faster decoding, High storage capacity	Shamir's (k,n) secret sharing algorithm to ensure security. Sets threshold for compatibility with standard decoder. Proposed color QR code generation algorithm

4. Discussion and Conclusion

4.1 Discussion

Several studies on the topics of the QR Code beautification research are discussed. During the beautifying process of the QR code, saliency regions are always taken into consideration when embodied trends are embodied, creating more visually pleasant results. The shortcomings encountered during the literature study are listed below:

- Enhancing the visual quality of QR codes compromises the decoding rate. There is a need to design a QR code that produces a visually pleasing appearance and has a high accuracy of decoding information at the same time.
- There is a size constraint of the embedded picture compared to the full image. It affects the visual quality of generated QR codes.

- During decoding, the luminance values change for particular pixels. The QR code may undergo a loss of edge information for images with a particular pixel at certain brightness levels.
- The color conversion used for color image beautification increases noise in code. So there should be some optimization to improve the visual quality.
- Existing QR codes are prone to several attacks by malicious users. There is a scope for enhancing the security features in QR code generation.

It is a big challenge to improve the QR code to produce a pleasant visual appearance without impacting the decoder efficiency and at the same time to improve security.

4.2 Conclusion

This paper aims at reviewing different approaches for QR code beautification to develop a better framework. The basics of QR codes will help understand the encoding and decoding process of QR codes. The encoding and decoding process of the QR code should be considered before modeling the beautification framework. Various methods and techniques are used for embedding pictures on QR codes but there is still scope for colored QR codes. QR code recognition from photographs is a difficult task. Some work can be done using machine learning algorithms for better recognition to improve the decoding rate. There are three aspects to looking into QR codes: beautification, decoding rate, and security. Many researchers have proposed their solutions to solve the problem, most approaches concentrate on only two aspects. Either QR codes are visually pleasing with a high decoding rate or they are beautified and secured. There is a need to design a QR code framework that produces a visually pleasing appearance, a secured and has high accuracy in decoding information.

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