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A Novel Information Imbedding and Recovering Method for QR Code based on Module Subdivision

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Abstract. *Among various kinds of bar code, Quick Response (QR) code is the most widely used one in our daily lives for information sharing. Though widely used, the standard QR code has a very serious problem, which is the lack of information security strategy. Therefore, anti-counterfeiting information are often involved as supplementary message distributed with the QR code together. Existing methods for the supplementary message embedding and recovering either support QR code as digital image only (e.g., the least significant bits based watermarking), or will not only do harm to the visual effect of the QR code but also consume a lot of computational resources (e.g., the frequency domain based method). In this work, a new five-in-one QR code and its writing/reading method is proposed based on the idea of module subdivision. The proposed QR code appears nicely, and the supplementary message can be successfully recovered with very low computational complexity from the QR code even if it undergos modification resulting from printing, liquid crystal displaying or scanning. Experiments demonstrate the effect and efficiency of the proposed method. Though aiming for security improvement of the QR code, the proposed method can be used in other QR code based applications for the purpose of storage capacity improvement.*

Keywords: QR code, Anti-counterfeiting, Storage capacity improvement, Module subdivision.

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1. **Introduction.** Bar codes are important media tools for information sharing. Among various kinds of bar code, Quick Response (QR) code is the most widely used one in our daily lives nowadays. The reasons for the popularity of QR code can be summarized as follows. Firstly, QR code is designed to be an automatic technique with high accuracy, reading speed and reliability [1]. These features laid a solid foundation for QR code based applications. Secondly, the development of mobile devices (e.g., smart phones) and the market which uses these devices for payment offered a well environment for the usage of QR code. Thirdly, the cost for the usage of QR code is very low. As we know, there are well defined standards, such as the "ISO/IEC 18004:2006" [2]. Abide by the standard, open source softwares, like ZXing[1], QRencode [2] and ZBar[3], for QR code

[1]https://github.com/zxing/zxing
[2]https://github.com/fukuchi/libqrencode
[3]https://github.com/ZBar/ZBar

encoding and decoding are very mature. Therefore, QR code can be generated easily before it is distributed through Internet or, in most cases, printed for sharing with little cost. Then, it also can be decoded conveniently by devices with a digital camera, which is used to capture a QR code image and get the shared message.

Though widely used, the standard QR code has a very serious problem, which is the lack of information security strategy. This is because, in our perspective, the QR code is born to be an open tool for information sharing. However, it also makes the counterfeiting of QR code very easy and leads to some information security problems. Please see a survey [3] for a better description of the security problem regarding to the QR code.

To solve the problem, a novel QR code based anti-counterfeiting solution was proposed in our previous work [1], where digital signature and Least Significant Bits (LSB) based watermarking techniques were used to achieve information authentication. However, since the LSB requires the QR code remains unchanged during its entire life time (e.g., from its generation by a merchant to it is read by a customer) in order to extract the embedded message, the proposed method was not suitable for the authentication of the QR code undergone print-and-scan operation, where the gray/color value of the captured QR code may be different from the original one due to variations such as illumination. In this paper, we aim to solve this problem.

The rest of the paper is organized as follows. In Section 2, basic principles and works related to ours are introduced. Section 3 presents the proposed method in details. Experiments and results are given in Section 4. Section 5 concludes the paper.

2. **Fundamental and Related Work.** Given a message M (i.e., a string of characters), we refer the procedure that generating a QR code Q from M to as encoding. Accordingly, M is called the encoded message. As a reverse process, extracting M from Q is referred to as decoding. There are totally 40 versions of QR code, the higher version means the bigger data capacity of a QR code. More details of a standard QR code can be seen in [2].

Suppose we want to store a supplementary message S (e.g., a signature string) along with M encoded in a QR code which can resist the print-and-scan operation, a straightforward idea, as proposed in [4], is appending the S to M, and encoding them together as a QR code. But in this case, the version of QR code would become very high and thus difficult for processing. Fig. 1 shows such an example. Namely, Fig. 1(b) illustrates a QR code of version 10, which is used to share a message (i.e., "https://www.fjut.edu.cn/") the same as that encoded in a Version 5 QR code depicted in Fig. 1(a). While in order to store a supplementary 256-byte signature string, a much higher version is required, which makes the module of QR code showed in Fig. 1(b) much smaller than that shown in Fig. 1(a) when the two QR codes are in the same size.

Another solution is embedding S into the frequency domain of QR code image [5, 6, 7], which is a solution most related works adopt. The reason is that the data embedded in the frequency domain of image can live with the print-and-scan process and successfully be recovered. But, as shown in Fig. 2(a), the QR code with data modification in the frequency domain appears differently from the original one. In other words, the frequency domain based data hiding techniques will do harm to the visual effect of QR code. Besides, compared with spatial domain based method, the frequency domain based method often suffers from high computational complexity, which is a critical problem for power limited bar code devices.

Lin [8] introduced a new QR sharing method by splitting the secret and conveying them with QR codes in the distribution application. However, we aim to embed a supplementary

(a) (b)

FIGURE 1. Two standard QR codes. (a) A QR code of version 5; (b) A QR code of much higher version than the one shown in (a).

(a) (b)

FIGURE 2. QR codes embedded with supplementary message by (a) watermarking in frequency domain [7] and (b) replacing the black modules by specific textured patterns [9].

message with just one QR code, rather than multiple ones as mentioned in [8]. But it offered a possible direction to solve our problem.

The work proposed by Tkachenko et al [9] is the one closest to ours, Fig. 2(b) depicted a two-level QR Code proposed by them, whose writing/reading method is very complicated, as well as the appearance.

In order to simultaneously embed a supplementary message S to a given QR code and do no harm to its visual effect, a novel spatial domain based method is proposed in this paper. The core idea is using multiple QR codes to encode S, then these QR codes will be merged with the original QR code based on a module subdivision strategy. We refer to the proposed QR code as five-in-one QR code, because, tough not mandatory, S will be evenly divided into 4 substrings in a general case. Along with the original message M, the five strings will be encoded in five QR codes of the same version, and then merged into one, from which both S and M can be recovered successfully. See Section 3 for further description.

3. **Proposed Method.** In this section, we first provide a brief introduction of our module subdivision scheme in Section 3.1, then the proposed five-in-one QR code writing and reading methods will be given in Section 3.2 and Section 3.3 respectively.

3.1. **Module subdivision scheme.** A standard QR code is consisted of many white-and-black squares, which called modules. Most of the modules are used to present data, namely, white one for 0 and black one for 1. Others are function modules used for locating,

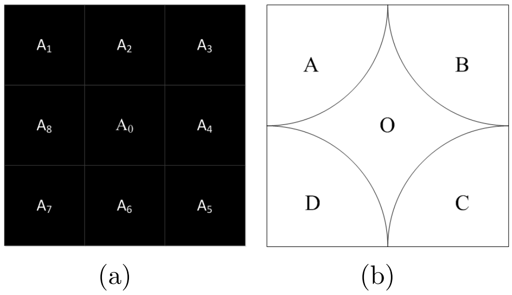

FIGURE 3. QR code module subdivision strategys. (a) A traditional 9-square subdivision; (b) One of the subdivision strategy in the proposed method.

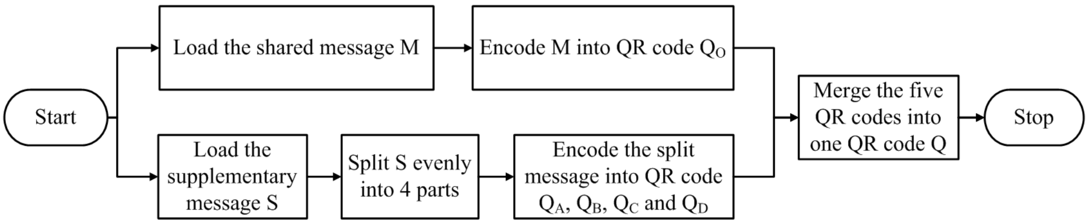

FIGURE 4. The pipeline of the five-in-one QR code writing method.

timing and alignment, etc [2]. All modules are in the same size and are corresponding to at least one pixel in the digital image. If a module consists of multiple pixels, which is a normal case, we can divide it into sub-regions. A commonly used strategy is that if we subdivide a non-function module evenly into 9 squares, and keep the center one unchanged, then we can modify the other 8 squares as we want, which will hardly cause any effect to its readability. With the help of this feature, background image can be added to a QR code as introduced in references such as [1, 10, 11]. While, in this paper, we use it to store additional message.

Fig. 3(a) shows the traditional 9-square subdivision strategy of a black module of QR code, where the center square A_0 is the one which should be maintained. By contrast, Fig. 3(b) shows one of our subdivision strategys, where region O will be the same as the original QR code, and regions A, B, C and D are used to represent the four QR codes which encode the split supplementary message.

3.2. **The five-in-one QR code writing method.** The pipeline of the proposed five-in-one QR code generation can be seen in Fig. 4, which is very simple and intuitive. Specifically, given a message M and a supplementary message S as inputs, the system try to generate a QR code Q as output, from which both M and S can be recovered successfully, on the assumption that the QR code may undergo print-and-scan process.

Benefit from the subdivision features mentioned above, we can use regions around the center area to represent supplementary information. But it would be a bad choice if we just put the supplementary data there directly in terms of binary bits, because the lack of data verification and correction mechanism would hardly ensure the recovery of important data such as the signature. While message encoded in the QR code can live with data errors to some extent, thanks to the reed-solomon codes [12] based error correction mechanism. So, in our method, we split S and then encode them as QR codes. The output of the system is a five-in-one QR code by merging the five QR codes into one. And the proposed merging strategy is given in Algorithm. 1.

Algorithm 1: Merging method of the five-in-one QR code

Input: Five QR codes Q_O, Q_A, Q_B, Q_C and Q_D of the same version, a desired width w of a module of the output.

Output: A five-in-one QR code Q.

initialize a square image Q of width $W = w \times N_O$, where N_O is the number of modules of Q_O in a row;

divide Q into $N_O \times N_O$ region and let $Q_{i,j}(1 \leq i, j \leq N_O)$ be the module of i_{th} row, j_{th} column, whose center coordinate is $(x_{Oij}, y_{Oij})(1 \leq x_{Oij}, y_{Oij} \leq W)$;

subdivide $Q_{i,j}$ into four square regions whose center coordinates are (x_{Aij}, y_{Aij}), (x_{Bij}, y_{Bij}), (x_{Cij}, y_{Cij}) and (x_{Dij}, y_{Dij}) respectively (in the order of top left, top right, bottom right and bottom left);

foreach *module* $O_{i,j} \in Q_O$*, where* i *and* j *are the row and column indexes of modules and meet* $1 \leq i, j \leq N_O$ **do**

  if $O_{i,j}$ *is a function module* **then**

    draw a $w \times w$ module on Q centered at (x_{Oij}, y_{Oij}) with the same color as $O_{i,j}$;

  end

  else

    let $A_{i,j}$, $B_{i,j}$, $C_{i,j}$ and $D_{i,j}$ $(1 \leq i, j \leq N_O)$ be the i_{th} row, j_{th} column module of Q_A, Q_B, Q_C and Q_D respectively, draw five patterns located at (x_{Oij}, y_{Oij}), (x_{Aij}, y_{Aij}), (x_{Bij}, y_{Bij}), (x_{Cij}, y_{Cij}) and (x_{Dij}, y_{Dij}) on $Q_{i,j}$ with the same color as $O_{i,j}$, $A_{i,j}$, $B_{i,j}$, $C_{i,j}$ and $D_{i,j}$, and make sure the patterns not only have no overlap among each other but also consist of at least three pixels;

  end

end

return Q;

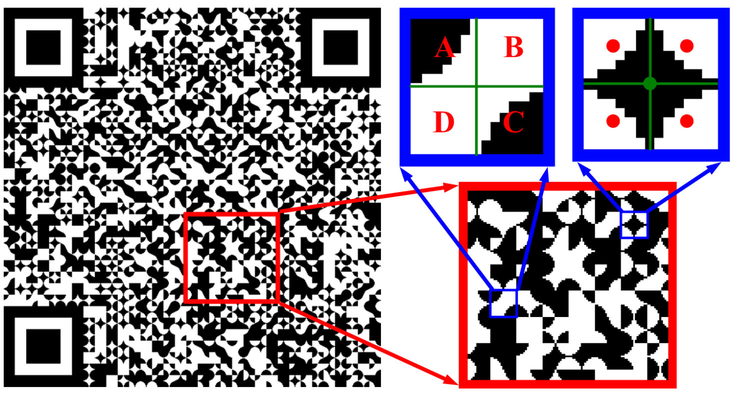

FIGURE 5. An example of the proposed five-in-one QR code.

An example of the proposed five-in-one QR code is illustrated in Fig. 5. The region marked with blue rectangle shows a module of the QR code. As can be seen, in order to achieve the subdivision effect shown in Fig. 3(b), each module is further subdivided into four sub-ones like the regions labeled with A, B, C and D in Fig. 5, which corresponding to the QR codes Q_A, Q_B, Q_C and Q_D in Algorithm. 1, and a fan shape is used as the pattern located at each red dot shown in the figure.

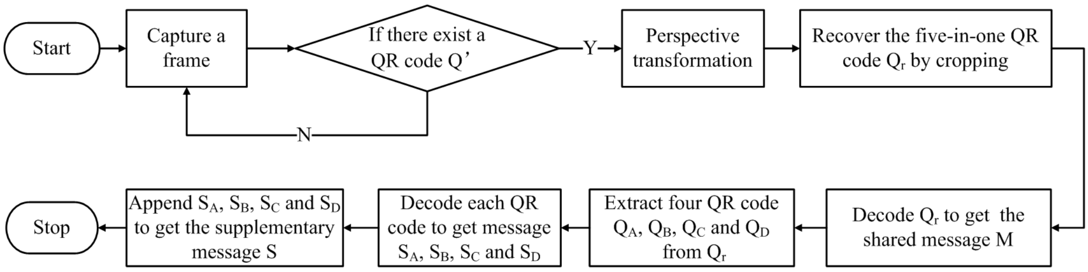

FIGURE 6. The pipeline of the five-in-one QR code reading method.

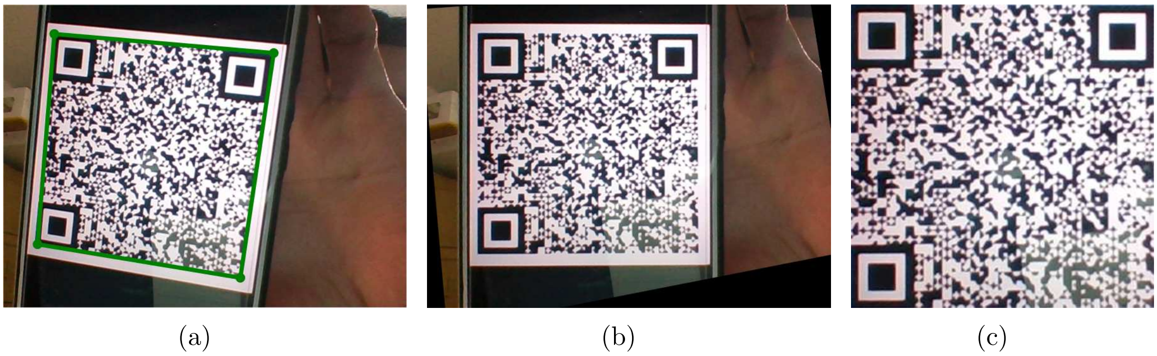

FIGURE 7. Recovering a QR code from the image captured by digital camera. (a) Recognized QR code and the four corner points marked with green dots by ZBar; (b) The output of the perspective transformation using points identified in (a); (c) The square QR code cropped from (b).

3.3. **The five-in-one QR code reading method.** Normally, after been generated, the QR code Q may be distributed in multiple forms, and captured as QR code Q' waiting for the decoding. For example, as a digital image, Q can be shared though Internet, and normally Q' will be the same as Q. But in most cases, Q will be printed or displayed on a screen, where Q' can hardly be the same as Q.

If a method can decode a printed QR code successfully, it will also suitable for QR code in the form of digital image. So in this Section, we aim to read a five-in-one QR code printed on papers or shown on screens, and get both the shared message M and supplementary message S. The pipeline of the proposed reading method is depicted in Fig. 6. Specifically, given a frame image captured by the digital camera as shown in Fig. 7(a), we will find a possible QR code in the frame. As long as a QR code Q' has been found, it is easy for us to get the four corner points (see green dots in Fig. 7(a)). Then the perspective transformation and cropping operations will be adopted to recover a square QR code Q_r. Fig. 7(b) and 7(c) demonstrate the outputs of the transformation and cropping respectively.

For most QR code reading tools, such as ZBar, the decoding result of Q_r directly will be M since we keep the center of each module unchanged. While the recovering process of S is actually the inverse of the merging method proposed in Algorithm. 1, namely, the information written in the subdivisions of each non-function module should be read. Since the function modules are not modified, we can easily get the width w of a regular module in Q_r. With the help of w and the width of the Q_r, we can find the center of each subdivision and further recover the substrings abiding by the standard of QR code. Finally, S is the combination of each substrings.

(a) (b) (c) (d)

FIGURE 8. A 256-byte supplementary message is split and encoded in (a), (b), (c) and (d) respectively.

(a) (b)

FIGURE 9. Two five-in-one QR codes with the (a) triangular and (b) discoidal patterns respectively.

4. **Experiments and Results.** In order to validate the proposed method, various experiments are carried out on a common laptop with an Intel Core i7 processor (3.5GHz), 8 GB memory, and a build-in 720p HD camera. QRencode (version 3.4.4) and Zbar (version 0.10) are used to implement the encoding and decoding of QR code. The OpenCV library [4] is used to fulfill basic image processings, such as the perspective transformation.

Firstly, Fig. 8 shows the four QR codes which encoded the message split from a 256-byte signature string. Then along with the QR code shown in Fig. 1(a), the five QR codes are merged into a proposed five-in-one QR code according to Algorithm 1. Fig. 9(a) and 9(b) illustrate two resulting five-in-one QR codes with triangular and discoidal patterns respectively.

To validate the performance of the reading method, five-in-one QR codes in different sizes and with different patterns are either printed on papers or shown on screens for scanning. Besides, different kinds of cameras including the one on the laptops and on some mobile phones are used for the testing, and both ZXing and ZBar, which are two most popular decoding toolkits nowadays, are adopted. The results showed the average accuracy for the reading of the proposed five-in-one QR code is 97.8%, which is pretty good for a real-world application.

[4]https://opencv.org/

5. **Conclusion and Future work.** In order to store an additional message supplementary to a given message encoded by QR code, a new five-in-one QR code is proposed in this paper. A major advantage of the proposed QR code is that the supplementary message can be successfully recovered even if the code undergos modification resulting from printing, scanning, or liquid crystal displaying. Based on the idea of module subdivision, both writing and reading methods of the five-in-one QR code are introduced in the paper to achieve storage capacity improvement without promoting the version of QR code. Other than frequency domain based methods, the proposed method modifies a standard QR code in its spatial domain, which can not only ensure a pleasure appearance of the QR code, but also keep a low computational complexity. The effect and efficiency are proved by a variety of experiments in different environments. Though aiming for security improvement of the QR code, the proposed method can also be used in other QR code based applications for the purpose of storage capacity improvement. In the future, we want to add color images as background to the proposed five-in-one QR code to express its visual semantics.

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