

Design of a Heterogeneous QR code for Internet of Things Based on Digital Watermarking Techniques

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Keywords: Internet of Things, QR code, object identifications, watermark, Discrete Cosine Transform, Quadrature Amplitude Modulation, Discrete Fourier Transform, heterogeneous QR code.

Abstract. A systematic solution based on the design of a heterogeneous code is proposed to promote the unified governance foundation of the existing Internet of Things (IoT). The proposed scheme enables advanced functionalities and maintains the compatibility with applications of the existing identifications (QR code) of things in IoT. The heterogeneous QR code is generated by invoking digital watermarking technique which embed a so called IoT standards code to the QR code. The result has shown that the heterogeneous QR code is backward compatible which implies that the embedding of the standards code does not introduce any reading difficulties to the original QR code. Moreover, a preprocessing scheme based on digital modulation is proposed for the standards code. The result has shown that the preprocessing is capable of enhancing the bit loading capability for standards code when given a fixed length of watermark for the sake of maintaining an acceptable performance.

Introduction

With the rapid development of the Internet, Internet of Things (IoT) has become one of the most promising areas in the field of information technology (IT). It is called the third wave of world information industry after the computer and the Internet [1-3]. At present, there are multiple *identification* schemes to identify a physical object in IoT. Each scheme follows their own standards and are independent with the others. Popular standards include object identifier (OID), Ecode, Handle and etc., which enable retrieving information from the Internet and deliver dynamic services [4]. Besides, there are several types of carriers for object identifications, such as barcode, two-dimensional (2-D) code, RFID (Radio-Frequency Identification), NFC (Near Field Communication) and etc. The 2-D code, typically the Quick Response code (QR code), is an image code which is ubiquitous in our daily life. It provides more cost-effective services and offers several potential advantages over other alternative technologies [5].

The diversity of identification standards leads identifiers and its applications towards a more smart and flexible fashion. However, the lack of a shared standards that regulates various IoT markets employing different identification schemes could result in serious problems. For example, conflicts may arise when objects equipped with different identifiers are applied in a shared environment where they need to connect and share the data. In the light of aforementioned problems, we take the advantage of QR code as an example of identifier carrier and propose a systematic solution based on the design of a heterogeneous QR code.

Our proposed method take the advantage of error correction capability of QR code as a virtual space for appending extra information [6]. It embeds a so called standards code to the existing QR code of an object. By introducing a standards code and the corresponding standard, various IoT markets would be compatible with each other, where objects identified by different schemes would be connected. Furthermore, the proposed heterogeneous identifier scheme ensures the compatibility with existing applications associated with initial objects identifiers. As to QR code, the embedded standards code does not interfere the QR code reader to extract the information from the original QR code.

Four sections are included in this paper: Section 1 discusses the methodology of the proposed scheme and introduces associated techniques, namely, DCT-based digital watermarking technique and modulation-based standards code preprocessing; Section 2 presents the process of generating the heterogeneous code and explains associated methods; Section 3 discusses the result and illustrate the achievement; Section 4 briefly summaries this paper and proposes some possible applications related to our contribution. Possible future works are included as well.

Methodology

The basic idea of the proposed method is to design a heterogeneous code which combines the existing QR code and the standards code by invoking digital watermarking techniques. Fig. 1 shows the diagram of the proposed scheme. As to the generation of a heterogeneous QR code, the QR code of an item is generated as the same as it was before, while the standards code which is basically a binary sequence is preprocessed firstly in order to generate a watermark providing good performance. Then, the digital watermarking process is invoked to embed the watermark conveying the standards code onto the QR code. At the detection side, the information associated with the QR code of an item is decoded in the way as it was, while the standards code is detected with the operation of watermarking extraction and is then recovered by performing the inverse operation of preprocessing. Basically, the proposed method relates to two techniques, namely, DCT-based digital watermarking and modulation-based digital preprocessing.

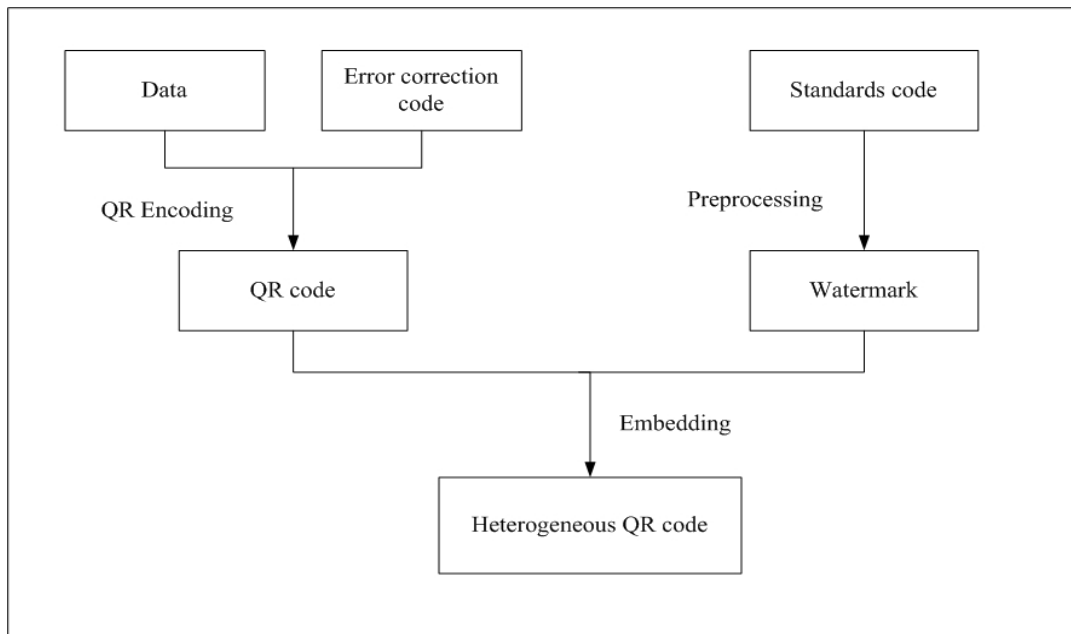


Fig. 1 The block diagram of generating a heterogeneous QR code

Digital watermarking has been extensively researched and many watermarking schemes have been proposed. The algorithm based on discrete-cosine transform (DCT) is one of schemes that provides a high robustness and very low perceptibility [7]. DCT is a linear transform that allows a spatial signal to be represented in the frequency domain. Two-dimensional DCT (2D-DCT) and its inverse manner are defined as:

$$F(u, v) = \frac{4C(u)C(v)}{N^2} \sum_{p=0}^{N-1} \sum_{q=0}^{N-1} f(p, q) \cos \left[\frac{(2p+1)u\pi}{2N} \right] \cos \left[\frac{(2q+1)v\pi}{2N} \right], \quad (1)$$

$$f(p, q) = \sum_{u=0}^{N-1} \sum_{v=0}^{N-1} C(u)C(v)F(u, v) \cos \left[\frac{(2p+1)u\pi}{2N} \right] \cos \left[\frac{(2q+1)v\pi}{2N} \right], \quad (2)$$

respectively, where $C(x) = 1/\sqrt{2}$, if $x = 0$; $C(x) = 1$, if $x \neq 0$. In *DCT-based watermarking*, the watermark is usually embedded by modifying a group of DCT frequency coefficients of the host signal following:

$$I_l^W = I_l \times (1 + \alpha W_l), \quad l = 0, 1, \dots, L-1, \quad (3)$$

where L is the total number of elements of the watermark. α indicates the watermarking strength. W_l represents the l -th element of the watermark. I_l is the l -th DCT coefficient chosen to be modified, while I_l^W is the value of the resultant corresponding frequency coefficient.

Modulation-based digital preprocessing is used to generate the element of watermark W_l from the standards code. As is discussed above, it can be argued that the property of the watermark would significantly affect the imperceptibility of the watermark. It can be inferred from Eq. 3 that given an embedding strength α and a chosen group of frequency coefficients, the larger value of watermark W_l , the more change to the host signal. By noticing this, we invoke a modulation-based digital preprocessing to transform the binary standards code sequence to a sequence that exhibits a near Gaussian distribution with zero mean.

M-ary QAM (quadrature amplitude modulation) maps each of $\log_2 M$ binary bits to one of M symbols with unique combinations of phase and amplitude. Therefore, each single symbol is capable of representing $\log_2 M$ -bits standards code. This implies that increasing the value of M could increase the bit load capacity for the standards code. To simplify the issue, we use 4-QAM mapping in this work. Therefore, the binary standards code bit sequence are grouped in two's so that they can be mapped to the corresponding symbols. For example, the standards code bit sequence (1,0,0,1,1,1) is grouped into three groups (10,01,11), and each of the 2-bits symbol is mapped to a complex-valued symbol according to Table 1, which therefore results in a symbol sequence as $(-\sqrt{2}/2 + j\sqrt{2}/2, \sqrt{2}/2 + j\sqrt{2}/2, -\sqrt{2}/2 - j\sqrt{2}/2)$.

Table 1. The principle of 4-QAM mapping

2-bits symbol	00	01	10	11
4-QAM symbol	$\frac{\sqrt{2}}{2} + j\frac{\sqrt{2}}{2}$	$\frac{\sqrt{2}}{2} - j\frac{\sqrt{2}}{2}$	$-\frac{\sqrt{2}}{2} + j\frac{\sqrt{2}}{2}$	$-\frac{\sqrt{2}}{2} - j\frac{\sqrt{2}}{2}$

Inverse discrete fourier transform (IDFT) is a technique that is used to generate the orthogonal frequency division (OFDM) signal in the digital domain. IDFT of a N -length vector $\mathbf{X} = [X_0, X_1, \dots, X_n, \dots, X_{N-1}]^T$ is defined as:

$$x_k = \text{IDFT}\{\mathbf{X}\} = \frac{1}{\sqrt{N}} \sum_{n=0}^{N-1} X_n \exp^{j\frac{2\pi}{N}nk}, \quad k = 0, 1, \dots, N-1. \quad (4)$$

It can be referred from Eq. 4 that an OFDM signal is the superposition of sinusoid signals carried on a number of orthogonal subcarriers which are basically independent with each other. According to the central limit theorem, an OFDM signal can be considered to be Gaussian distributed if the amplitude of the subcarriers are independent and identically distributed random variables and the number of subcarriers is large enough [8]. Hence, it can be inferred that given a pseudorandom binary

sequence, after undergoing M -ary QAM mapping with large value of M and IDFT with large value of N , the binary sequence is transformed into a pseudorandom sequence exhibits Gaussian distribution with zero mean.

Implementation

The basic idea of generating the heterogeneous code is to convert the binary standards code sequence \mathbf{s} to a near-Gaussian distributed pseudorandom sequence \mathbf{W} which is then used as the watermark to modify a group of DCT frequency coefficients \mathbf{I} of a QR code. Finally, convert the resultant DCT matrix \mathbf{I}^W back to the special domain and then form the heterogeneous QR code. The flowchart of the process is shown is Fig.2. The process can be divided into three parts: generate DCT of a QR code, generate watermark from the standards code and form the heterogeneous code.

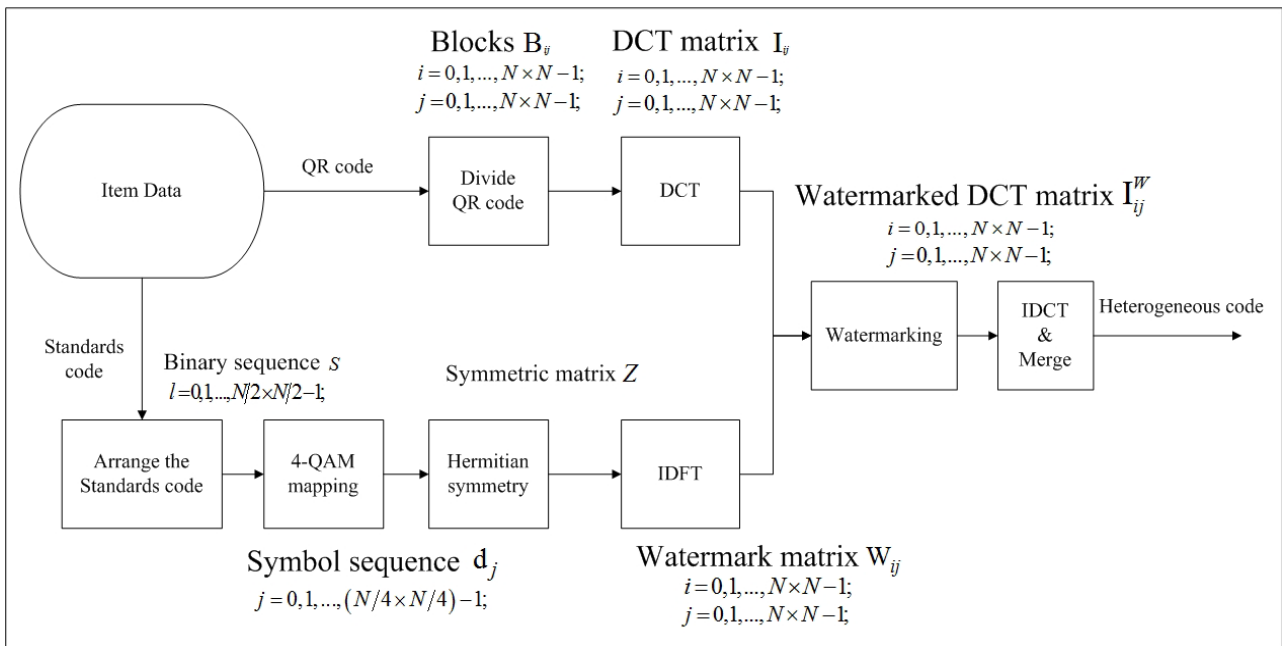


Fig. 2 The flowchart of generating a heterogeneous QR code

- (i) Generate DCT of a QR code:
 - Step 1.1 Divide the QR code having size of $M \times M$ into $N \times N$ blocks, and each block \mathbf{B}_{ij} , $i = 0, 1, \dots, N \times N - 1, j = 0, 1, \dots, N \times N - 1$ having size of $K \times K$, where $K = M/N$;
 - Step 1.2 Apply 2D-DCT in Eq. 1 to all blocks respectively, generating DCT coefficients array \mathbf{I}_{ij} for each corresponding block \mathbf{B}_{ij} ;
- (ii) Generate the watermark from standards code:
 - Step 2.1 Extract the standards code assigned to an item;
 - Step 2.2 Arrange the binary standards code and form a binary sequence $\mathbf{s} = [s_0, s_2, \dots, s_{L-1}, s_{L-1}]$, $s_l \in \{0, 1\}$, where $L = N/2 \times N/2$ in order to simplify the watermarking;
 - Step 2.3 Group adjacent bits in \mathbf{S} by two and map each of them to a 4-QAM symbol according to Table 1 and generate the symbol sequence $\mathbf{d} = [d_0, d_2, \dots, d_{J-1}]$, where $J = N/4 \times N/4$;
 - Step 2.4 Reshape \mathbf{d} and form a matrix \mathbf{Z} of size $N \times N$ following the principle that each column of \mathbf{Z} is Hermitian symmetry;
 - Step 2.5 Apply IDFT on all columns in \mathbf{Z} and generate the watermark matrix \mathbf{W} of size $N \times N$.
- (iii) Form the heterogeneous code:

- Step 3.1 Use each element W_{ij} in \mathbf{W} to modify the DC component in each 2D-DCT array, following $\mathbf{I}_{ij}^W(0,0) = \mathbf{I}_{ij}(0,0) \times (1 + \alpha W_{ij})$ $i = 0,1, \dots, N - 1$, $j = 0,1, \dots, N - 1$;
- Step 3.2 Apply IDCT on each modified DCT coefficient matrix \mathbf{I}_{ij}^W and merge the resultant spatial blocks to form the heterogeneous QR code.

Results and discussions

An example of generating a heterogeneous QR code is demonstrated in this section in order to show the implementation of our proposed method in a more straightforward fashion. For the sake of simplicity, the achievable performance is illustrated by using simple coefficients. As to the host signal, we assume an existing QR code of size 256×256 . The QR code is divided into small blocks with each of them having size of 8×8 . The resulting 32×32 small blocks do not overlap with each other. As to generating the watermark, we assume the standards code as a binary sequence having length of 16×16 . By mapping each two binary bits to a 4-QAM symbol, we obtained a symbol sequence having length of 8×8 . The symbol sequence is then reshaped to form a matrix of size 32×32 following Hermitian symmetry. Finally, IDFT of size 32 is applied on each column in the matrix, generating a real-valued matrix having a total number of 32×32 elements with each of them represents an element of the watermark. As to the watermarking, 2D-DCT of size 8×8 is applied to each small block of the QR code, generating 32×32 DCT coefficients matrix with each matrix having 8×8 elements. 32×32 number of DC components are modified by the corresponding element in the watermark following Eq. 3. In order to illustrate the advantage of the proposed digital preprocessing, the watermark strength is adjusted to $\alpha = 0.2$, which is a relative large value for retaining a good imperceptibility of the watermark in the common scenario. Then, the heterogeneous QR code is generated by applying 2D-IDCT on each resultant DCT matrix and merge all blocks in spatial domain.

In Fig. 3, the subplot on the left shows the existing QR code generated online, while the resultant heterogeneous QR code is shown in the subplot on the right. It can be noticed that there is hardly perceptible change in the heterogeneous QR code compared to the one before being watermarked. This is because that a majority number of elements in the watermark signal have an amplitude approaching zero owing to the IDFT operation which has been illustrated in Fig.4. In Fig.4, the left plot shows the amplitude of a total number of 32×32 elements of the watermark. It can be seen that the amplitude of all elements is almost within the range of $[-0.5, 0.5]$. As to the probability, the plot on the right showed the histogram of the watermark, illustrating that a majority of elements of the watermark have an amplitude approaching zero. As a result, the change to the existing QR code is very small even though the watermark is embedded on the DC component which carries the majority of information.

To elaborate a little bit further, the proposed method is of flexibility. The size K of blocks, the length N of IDFT, the order M of QAM and the DCT coefficients used to embed the watermark are relatively flexible to choose. It could be argued that the performance of the proposed method varies with the value of aforementioned coefficients. For example, a large value of M with a large value of N would improve the imperceptibility of the watermark, benefited from the pseudorandom sequence having a more Gaussian-like distribution. Obviously, a better performance is achieved at the cost of high computing complexity which is always a trade-off.



Fig. 3 QR code and the heterogeneous code

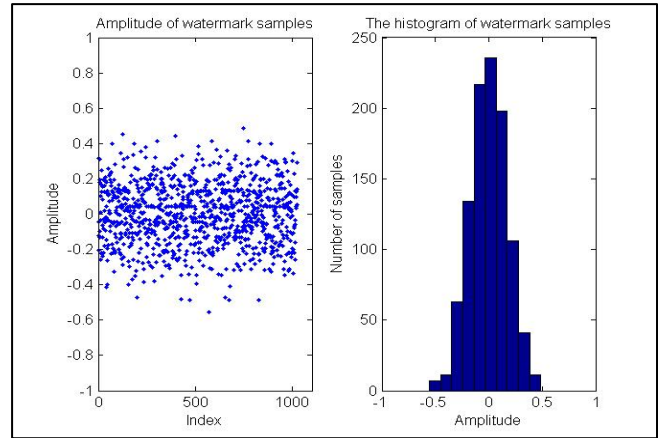


Fig. 4 The amplitude distribution of the watermark

Summary

This paper has proposed a systematic solution to promote the unified governance foundation of various IoT markets using different identification schemes. DCT-based digital watermark technique is invoked in order to achieve the backward capability of the heterogeneous QR code. Moreover, a modulation based preprocessing for the standards code is proposed. By introducing a standards code and the corresponding standard, various IoT things ranging from food to machines will be connected and will be able to exchange information. Furthermore, the proposed heterogeneous identification scheme ensures the compatibility with existing applications associated with initial objects identifiers. As to QR code, the embedded standards code does not interfere the QR code reader to extract the information from the original QR code.

Additionally, as a benefit, this method would enable developing value-added services based on the existing carriers of the identification so that support more flexible applications. This could be achieved by substituting the aforementioned standards code by additional information associated with new functions in a way which will be included in the future work. Additionally, a proactive work regarding at extracting the embedded information from the heterogeneous QR code has been launched and optimizing methods will be included in our future works. Furthermore, the trade-off between the cost and the achievable performance as is discussed in section 3 will be included in the future work as well.

Acknowledgment

Submitted by *Computer Network Information Center Chinese Academy of Sciences*. The financial support of the *CNIC Qing Nian funding* of CNIC_QN_1409 is gratefully acknowledged.

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