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Method of multiple-image hiding in QR code based on compressed sensing and orthogonal modulation

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ABSTRACT

In this paper, a method of multiple-image hiding in quick response (QR) code based on compressed sensing (CS) and orthogonal modulation is presented. Using this approach, it is possible to preserve the multiple-image information perfectly in QR code. The application of CS theory can significantly reduce the amount of data processing when an image is reconstructed, and also brings a lot of convenience for the post-processing. In order to extract the images separately, orthogonal basis matrices are used to modulate the detected intensity sequences from the CS system. Hiding approach results in a QR code image which looks like normal, and the total data volume of multiple-image can be obtained after scanning and decoding the QR code. When the transpose matrix of corresponding orthogonal basis is used, the needed partial data can be extracted from the total data volume. It should be noted that only when the measurement matrix and orthogonal basis matrix are matched, the corresponding image can be reconstructed clearly. That means there are two security levels in this information hiding method. This method can also be used in the case when a huge image is divided into several parts to hide. Advantages of using orthogonal basis matrix are apparently, not only the redundant computation but also the amount of calculation can be diminished efficiently in the process of reconstruction. The feasibility of this method has been verified by the experiment, where a video projector is used to incorporate the random measurement matrices into the system.

1. Introduction

With the advent of information age, information processing capability and security are becoming increasingly important. How to process massive data and how to prevent illegal data access from unauthorized users are critical issues in modern society. In recent years, a variety of compression technology and optical encryption technology have been receiving considerable attentions [1–6].Currently, quick response (QR) code, invented by Toyota subsidiary Denso Wave, has been widely used in many appropriate applications to deal with real-time data [7,8] because it can be easily read by smart phones or tablets. And it is also reported to be applied in optical encryption [9–12].

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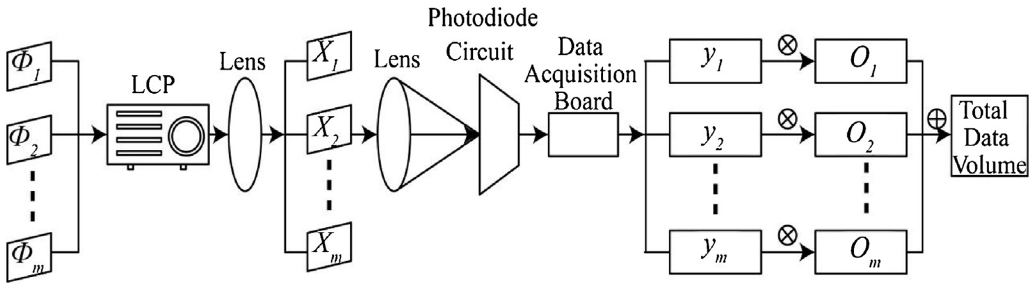

Fig. 1. Schematic and flow chart of coding phase;Φ_m: measurement matrices,X_m: block objects,y_i: measurement results,O_m: orthogonal basis matrices, LCP: liquid crystal projector,⊗: multiplier,⊕: summator.

With the further popularization of Andiord smart phones, QR code has growingly numerous applications in manufacturing, sales, logistics, storage, transportation and consumer product industry. Although it has robust fault tolerance and error correction capability, however, there are still a number of limitations and challenges that need to be solved. According to the coding standard [13], a QR code can only accept four types of input data, and the number of bytes that can be accommodated is restricted. A QR code consists of black and white square points as the basic binary information elements. The size of QR code varies with different QR code versions [13]. The minimum and maximum sizes are 21×21 and 177×177, and the number of points are proportional to the amount of information stored in the QR code. So, an image usually cannot be directly transformed to a QR code for the case that the amount of data which can be converted to a QR code is limited. Therefore, to improve the image information stored in a QR code, the compressed sensing (CS) theory [1–3] is put forward because some applications have proved that CS can noticeably reduce the number of bits to be transmitted and stored [14–20]. Furthermore, in recent years, the orthogonal codes, such as Hadamard matrix, Haar-wavelet-basis, etc, are utilized in the field of optical encryption, mainly in the decryption phase to extract the needed secret images [21–23].

In this paper, we propose a method that combines CS and orthogonal modulation to put the measured values of multiple-image into a QR code, which means that a QR code saving multiple-image information can be realized. In our setup, Hadamard matrix is applied to encode the sampling data of each sub-image, and then the total data volume is converted to a QR code. By scanning and decoding the QR code, the total data volume can be obtained again, and next it is used to extract the needed partial data utilizing the transpose matrix of corresponding orthogonal basis.

Some characteristics can be found in our method: First of all, although the data capacity of the QR code is constant, this method can greatly increase the amount of information stored in a QR code, and it becomes possible to store the multiple-image information in a QR code. Secondary, in the aspect of structural complexity, this device is more straightforward. We adopt a liquid crystal projector (LCP) instead of a digital micro-mirror device (DMD) in the system, it can incorporate the random measurement matrix into the system and adapt to the needs of active imaging system. The resolution of the reconstructed image can be easily changed by setting the size of random measurement matrix, so it can realize multi-resolution image reconstruction. Besides, due to the application of orthogonal modulation, for a complete image, the needed partial image can be reconstructed independently rather than rebuilding the complete image in prior, therefore it can reduce the redundant computation as well as the total amount of calculation. At last, this method increases the versatility of QR code applications. The security of this method is also well guaranteed because there are two security levels in the encryption scheme to ensure the security of the images. It can be widely used in life, such as personal information management.

2. Method

The method is composed of two phases of coding and decoding. The coding phase realizes to save information of multiple-image in a QR code while the decoding is opposite.

2.1. Coding phase

The schematic and flowchart of coding phase are shown in Fig. 1. In order to prove that the method can also be used for the sectional reconstruction of a single complex image, we divide a single image into many blocks to simulate multiple images processing. Here the object image is supposed to be divided into m blocks (X_1,X_2,. . .,X_m), they can also be regarded as m independent images, being put behind the first lens in turn. For each block image, we can represent it by a long one-dimensional vector with $N = n \times n$ rows, which is supposed to be the resolution size of the reconstructed image. A group of measurement matrices (Φ_1,Φ_2,. . .,Φ_m) is prepared, and each measurement matrix (with the size of $M \times N$) corresponds to one block image, where M represents the sampling numbers. A liquid crystal projector is utilized to project a set of pseudo-random pictures onto the block images, and these pictures are generated one by one from each row of these measurement matrices. According to the principle of CS, the measurement results of every block image can be written as

$$y_i = \Phi_i \times X_i, \;\; i \in [1, m]. \tag{1}$$