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QR codes blind deconvolution algorithm based on binary characteristic and L_0 norm minimization

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ABSTRACT

In recent years, QR code has been widely used in various society fields, and has provided great convenience in information exchange, commodity payment and website registration. However, the degradation of QR code images can cause difficulty in reading the code information. In this paper, we propose an alternating minimization restoration model for QR code images. Based on the binary prior, we use the binary characteristic and L_0 norm as the regularization terms, and introduce different auxiliary variables to make the complex model become solvable. The bi-level constraint of bar code image maintains the sparseness of image pixels and gradient. The experimental result shows that our algorithm has excellent effect on common blur kernels and multiple noise, and its performance is better than the state-of-the-art algorithms.

1. Introduction

With the rapid development of Tablet PC and smartphones, using two-dimensional code to exchange and delivery the information with mobile devices has been very popular. Invented by the Japanese company Denso–Wave in 1994 [15], QR Code (Quick Response), which is originally designed to allow high-speed component scanning to track vehicles during manufacturing, is one of the most important code protocol of two-dimensional code [23], and has attracted the attention of various fields in recent years. 1D bar code appeared in the early twentieth century [12], and greatly improved the data collection and information processing speed. But due to the information capacity constraints, the use of 1D bar code had to rely on the existence of the database and convenient network. In addition, 1D bar code is very inconvenient and inefficient to express Chinese characters. Compared with the traditional 1D bar code, QR code has the advantages of large information capacity, easy identification, high reliability, strong security, and low cost. Therefore, it is widely used in daily life, business activities, information transmission and other social fields. The QR code is detected by a two-dimensional image scanner and then is digitally analyzed by a processor. The general structure of QR code is shown in Fig 1, the stored information is extracted from the horizontal and vertical patterns of the 2D code image. The processor detects the position of the three big squares at the corners of the QR code image, and uses one smaller square (or multiple squares) to normalize the size, direction, and viewing angle of the image. Finally small dots in the QR code are converted to binary numbers and verified by using an error correction algorithm.

However, the degradation of the image in practice is ubiquitous, and inevitable, which affects the extraction of image information. Moreover, when the mobile device equipped with a camera scans a QR code image, it is prone to generate the motion blur (relative motion between the camera and the object) and defocusing blur (the object is not in the focal plane of the camera), which make the image not clear so that the processor cannot locate the patterns. Image restoration is one of the hot and intractable aspects in the domain of image processing, and researchers in this area has produced many excellent algorithms. In this paper, we study the blind restoration problem of QR code image. Under the condition that the blur kernel is unknown, the estimated kernel and latent image are obtained by alternately iterative minimization algorithm combining the binary characteristic and L_0 norm of the binary image.

The rest of this paper is organized as follows: The related work are described in Section 2. The minimization model based on binary prior and L_0 regularization is introduced in Section 3. The proposed alternative minimization algorithm is explained in Section 4. The experimental results are analyzed in Section 5. The conclusions are summarized in Section 6.

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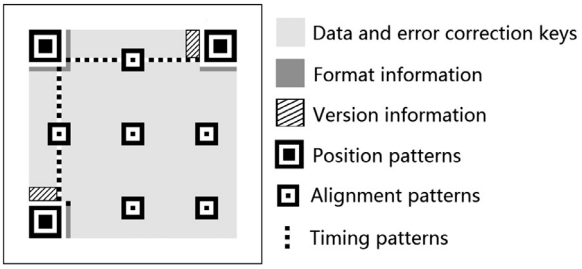

Fig. 1. General structure of the QR code.

2. Related work

Many excellent works have been done about the restoration of bar code. Esedoglu [3] considered a total variation based on a variational model to solve the bar code reconstruction problem. Krešić–Jurić [6] calculated statistical properties of edge detection error with a bar code polluted by speckle noise; Kim and Lee [5] proposed a method using a penalized nonlinear squares objective function to deblur the bar code signals. Liu and Sun [9] considered an iterative deconvolution algorithm based on the idea of bar codes as bi-level waveforms. But most of them only focused on one-dimensional codes, so cannot perform very well on the blind recovery of 2D code. In recent years, the 2D code recovery work has aroused some interest. Xu and McCloskey [27] improved the robustness of the 2D bar codes with motion blur based on coded exposure imaging. Liu et al. [10] presented a deblurring algorithm named the Increment Constrained Least Squares filter, which combined the bi-level constraint of the image. Sörös et al. [20] presented a fast restoration-recognition algorithm which blindly estimated the blur from the salient edges of the code in an iterative optimization scheme, alternating between image sharpening, blur estimation, and decoding. Gennip et al. [22] designed an algorithm that transformed the pattern required by the QR symbol system into a total variation regularization method, but their algorithm depended on the pattern of the known clear QR code image.

Although there is not much attention on the blind recovery of two-dimensional code images, there are many outstanding methods on the restoration of binary images such as text having similar features with QR codes. Li and Lii [8] proposed a novel statistical method, which was to adjust a deblurring filter until images blurred by an unknown linear filter become two tone. Shen et al. [19] observed the relationship between individual pixel values of binary images and the point spread function to minimize the global energy function, and computed the optimal solution of the convex relaxation based on PSD programming and the randomized-hyperplane method. Zhang [29] proposed an alternating minimization algorithm which introduced a new variable to enforce the image to be binary in the minimization model. Mei et al. [11] incorporated the knowledge of distinct pixel values of the original images into the general regularized least squares restoration framework. Xiao et al. [24] presented a fast and high-quality blind deconvolution method, which used high-order filters for document image regularization. Pan et al. [13] proposed an effective L_0-regularized prior based on intensity and gradient by observing distinct properties of text images to estimate the kernel and latent images.

In this paper, we introduced an effective method to restore the blurred and noisy QR code images. Considering the binary characteristic of QR code images, we incorporated binary constraints and L_0 norm as regularization terms into the alternating minimization model. Experimental results show that our method is obviously effective for QR code images restoration, and performs better than the state-of-the-art methods.

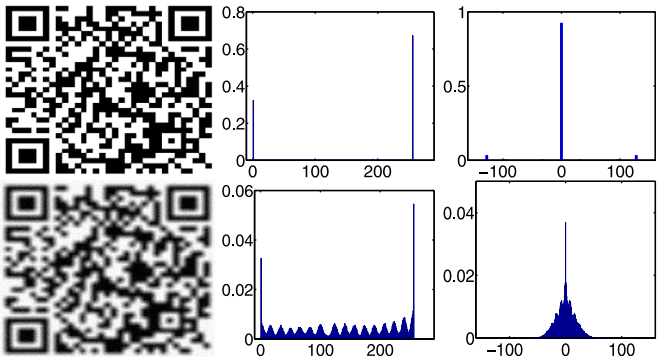

Fig. 2. Statistical property of code image. 1st rows: Original image, the histograms of its intensity and horizontal gradient. 2nd rows: QR code image with Gaussian blur, the histograms of its intensity and horizontal gradient.

3. L_0 regularization model based on binary prior

3.1. Image restoration model

Image degradation process is generally model into a degradation function with additive noise [4], which can be expressed as follows:

$$g = f * h + n \tag{1}$$

where $*$ is the 2D convolution operation. f, g represent the original and blurred images, respectively. n is the additive noise that can be expressed as a matrix. h is the point spread function (PSF). In practice, only the blurred image g is known, our aim is to estimate the real image f and the blur kernel h, which is really an ill-posed problem.

A lot of researches have indicated that the regularization methods have better characteristics in maintaining the edge and suppressing the noise of the image compared with other methods. A commonly-used restoration method is to construct an alternating minimization model with regularization methods, which can be expressed as follow:

$$\min_{f,h} \|h * f - g\| + \lambda R(f) + \rho R(h) \tag{2}$$

In Eq. (2), the first part is data fitting term that basically is expressed in L_2 norm. $R(f)$, $R(h)$ are the regularization terms of the latent image and the blur kernel. λ, ρ are the regularization parameters. For the regularization terms, Tikhonov regularization [21], total variation [17] all are frequently applied in the restoration work. The models based on Tikhonov regularization are quadratic, which makes the model easier to be solved and get the minimum, but leads to excessive smooth. TV method is more sparse than Tikhonov regularization, it can keep the sharp edge and other details of the image. However, the TV functions are always sophisticated, non-differentiable and nonlinear, the calculation will be very large scale for the complex images. So, much work applies sparse prior to regularize the images and kernels now [1,25,26].

3.2. L_0 regularization

In this paper, we use the sparse feature of QR code images as a prior knowledge for blind restoration. As a binary image, each pixel value can only take black or white, as shown in Fig. 2, there are two peaks at 0 and 255 in the gray histogram of the image, while the horizontal gradient histogram of the image has only zero peak. According to this observation, we choose L_0 norm proposed by Pan et al. [13] as the constraint to maintain its sparseness during the restoration process. In fact, for the real QR code image in Fig. 3, there is no zero peak in the gray histogram, but its gradient feature