Low resolution QR-code recognition by applying super-resolution using the property of QR-codes

Yuji Kato[1], Daisuke Deguchi[1], Tomokazu Takahashi[2], Ichiro Ide[1] and Hiroshi Murase[1]
[1] Graduate School of Information Science, Nagoya University, Japan
ykato@murase.m.is.nagoya-u.ac.jp, {ddeguchi, ide, murase}@is.nagoya-u.ac.jp
[2] Faculty of Economics and Information, Gifu Shotoku Gakuen University, Japan
ttakahashi@gifu.shotoku.ac.jp

***Abstract*—This paper proposes a method for low resolution QR-code recognition. A QR-code is a two-dimensional binary symbol that can embed various information such as characters and numbers. To recognize a QR-code correctly and stably, the resolution of an input image should be high. In practice, however, recognition of a QR-code is usually difficult due to low resolution when it is captured from a distance. In this paper, we propose a method to improve the performance of low resolution QR-code recognition by using the super-resolution technique that generates a high resolution image from multiple low-resolution images. Although a QR-code is a binary pattern, it is observed as a grayscale image due to the degradation through the capturing process. Especially the pixels around the borders between white and black regions become ambiguous. To overcome this problem, the proposed method introduces a binary pattern constraint to generate super-resolved images appropriate for recognition. Experimental results showed that a recognition rate of 98% can be achieved by the proposed method, which is a 15.7% improvement in comparison with a method using a conventional super-resolution method.**

***Keywords*-Super-resolution, QR-code recognition, binary constraint**

I. Introduction

Recently, QR-codes are seen everywhere around us. As shown in Fig. 1, a QR-code is a two-dimensional binary symbol that can embed various information such as characters and numbers [1]. So, it is widely used in systems such as manufacturing, logistics and sales. As shown in Fig. 2, we often capture a QR-code image with a mobile device, such as a cell-phone. To recognize a QR-code stably, the resolution of an input image should be high. In practice, however, recognition of a QR-code by conventional technique becomes difficult due to low resolution when the QR-codes are captured from a distance. To avoid this, it is necessary to develop a low resolution QR-code recognition technique. This technique can be used to recognize a QR-code on distant advertisements, guide signs, and so on.

Several researches have been conducted on the recognition of low resolution characters and barcodes, which take super-resolution approaches. For example, Okura et al. [2] proposed a method for character recognition from a low-resolution image sequence. This method generates a high resolution image from multiple low-resolution images.

Figure 1. Example of a QR-code "http://mist.murase.m.is.nagoya-u.ac.jp/".

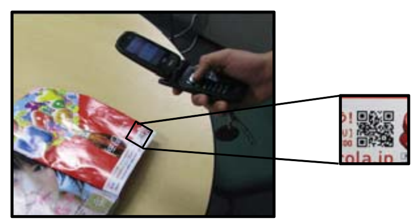

Figure 2. Capturing a QR-code by a built-in digital camera of a cell-phone.

Although the method aims to recognize characters, it does not use any constraint based on the properties specific to the target characters. Donaldson et al. [3] proposed a super-resolution method of text in video. To improve the accuracy of character recognition, the method uses text specific bimodal prior. Champagnat et al. [4] proposed a super-resolution method to improve the performance of barcode recognition by considering its one-dimensional structure. Since the QR-code has a two-dimensional structure, this method is not applicable to QR-codes. In this paper, we propose a QR-code recognition method using super-resolution by introducing constraints based on the property of a QR-code that it consists of a binary pattern only.

This paper is organized as follows: In Section 2, a super-resolution method using the constraint based on the binary property of a QR-code is described. In Section 3, we propose a QR-code recognition method using the super-resolution method. Experimental results are presented in Section 4, and discussed in Section 5. Finally, we conclude this paper in Section 6.

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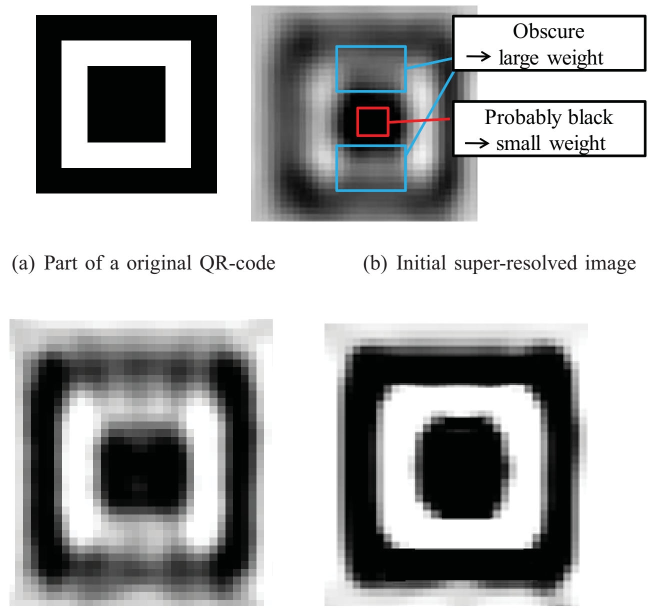
II. Super-resolution using the property of QR-codes

A QR-code is usually captured by a mobile device, so it is usually possible to capture a short continuous image sequence of it. Therefore, we assume that multiple images are available for the QR-code recognition.

Super-resolution is a technique to generate a high resolution image (super-resolved image) from multiple low resolution images by complementing information of pixels using the displacement caused by slight camera motions [5]–[7]. By applying the super-resolution technique for QR-code recognition, we expect that it will become possible to recognize a low resolution QR-code image.

Figures 3(a) and (b) show the original QR-code image and the observed image, respectively. Although the QR-code is originally printed or displayed as a binary image, it is observed as a grayscale image due to the degradation through the capturing process. Especially, the pixels around the border between white and black regions become ambiguous. This leads to the failure of QR-code recognition. To overcome this problem, the proposed method takes advantage of the property of QR-codes for super-resolution.



(a) Part of a original QR-code (b) Initial super-resolved image (c) ML super-resolved image (d) Ideal super-resolved image

Figure 3. Examples of super-resolved images.

A. Conventional super-resolution method

A Super-resolution method [8] based on ML (Maximum Likelihood) method is used in the proposed method. It is composed of two stages. First, a registered image is generated by aligning images of an input image sequence. Second, a super-resolved image is reconstructed by removing image blur from the registered image. In this reconstruction process, a super-resolved image is generated by minimizing the error function that evaluates the difference between the generated super-resolved image and the registered image. By considering the degrading process in a camera, the error function J is given by

$$J = \sum_{i=1}^{M'} \left[\boldsymbol{b}_i^{\mathrm{T}} \boldsymbol{h} - r_i \right]^2, \qquad (1)$$

where $\boldsymbol{h}$ is a column vector consisting of pixel values of the super-resolved image, and M' is the size of $\boldsymbol{h}$, $\boldsymbol{b}_i$ is a degradation vector in the capturing process, and r_i is the i-th value of the registered image.

B. Proposed super-resolution method using the binary pattern constraint

In the proposed method, the property of QR-codes is used in the reconstruction process of the super-resolution method. Since a QR-code is represented as a binary pattern, each pixel of an observed QR-code image should be either black or white. Therefore, we assume that any whitish pixel corresponds to a white pixel and any blackish pixel corresponds to a black pixel in the observed image. However, it is difficult to distinguish whether gray pixels correspond to black or white pixels. Therefore, the proposed method sets a large weight for gray pixels when the error is calculated. This will allow the reconstruction process to generate an appropriate image for the recognition. Following this assumption, we introduce a weighted error function J' as shown in Eq. (2), where the weight is determined by the intensity of each pixel.

$$J' = \sum_{i=1}^{M'} w(h_i) \left[\boldsymbol{b}_i^{\mathrm{T}} \boldsymbol{h} - r_i \right]^2, \qquad (2)$$

where the weight is decided according to the intensity x as

$$w(x) = \frac{4 \exp\left(-\alpha(x-128)\right)}{\left(1+\exp\left(-\alpha(x-128)\right)\right)^2}. \qquad (3)$$

This is the first derivative of a sigmoid function, and α is a parameter that determines the form of the function. Figure 4 shows the graph of the weight function $w(x)$. In this function, if the intensity is close to 0 or 255, the weight becomes small. If the value is close to 128, the weight becomes large. The reconstruction process for the proposed super-resolution method is performed by minimizing the error function J'.

III. QR-code recognition using super-resolution

This section describes the process flow of the QR-code recognition by the proposed method.

Figure 5 shows the process flow of the proposed method. The proposed method recognizes a QR-code from an input

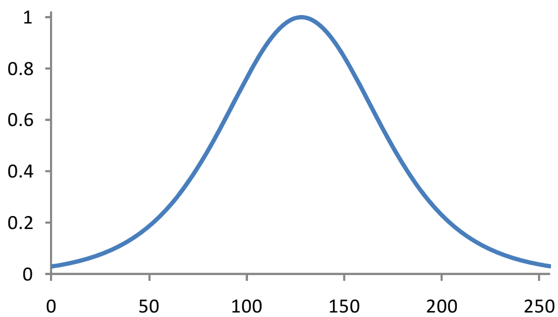


Figure 4. Weight function ($\alpha = 0.038$)

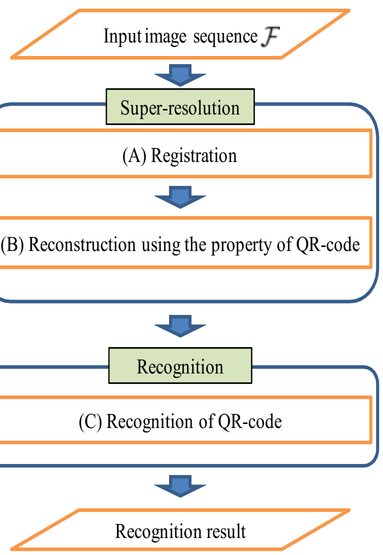


Figure 5. Flow chart of the proposed method.

image sequence $\mathcal{F}$. The method is composed of three processes: (A) registration, (B) reconstruction, and (C) recognition. The following sections explain details of each process.

A. Registration

The proposed method assumes that images in the input image sequence have little displacement caused by camera shake. To align these images, the displacements in the images are estimated in sub-pixel accuracy, and a registered image is generated by aligning them. Here, $\boldsymbol{f}^i \in \mathcal{F}(i = 1, \cdots, N)$ is the i-th image of an input image sequence $\mathcal{F}$, where each image is composed of M pixels, and the registered image includes M' pixels. First, each image $\boldsymbol{f}^i$ is converted into grayscale, and intensities are normalized within 0 to 255. Next, a high resolution image $\boldsymbol{f}'^i$ is generated by expanding to M' pixels from $\boldsymbol{f}^i$ by bi-cubic interpolation. Then a registered image $\boldsymbol{r}$ is calculated by averaging the aligned images $\boldsymbol{f}'^i$ based on sub-pixel displacements from the first image $\boldsymbol{f}^1$. POC (Phase-Only Correlation) [9] is used to calculate the sub-pixel displacements.

B. Reconstruction using the property of QR-codes

In the reconstruction process, a super-resolved image is generated by minimizing Eq. (2). A conjugate gradient method is used for minimization. The initial high resolution image $\boldsymbol{h}$ is a interpolated image of the first image $\boldsymbol{f}^1$ by bi-cubic interpolation.

C. Recognition of the QR-code

In the recognition process, the QR-code is detected from the super-resolved image. Finally, the embedded information in the QR-code is decoded by inputting the detected area to a QR-code decoder.

IV. Experiments

We prepared various printed QR-codes and their captured image sequences for the experiment. Using these image sequences, we evaluated the effectiveness of the proposed method.

1,600 image sequences including 20 kinds of QR-codes were prepared. Figure 7(a) shows an example of a QR-code image sequence used in this experiment. The resolution of a QR-code is denoted as X^2 ($= X \times X$ pixels) hereafter. The dataset contains QR-codes in 8 resolutions: 44^2, 46^2, $\cdots$, 58^2. Each image sequence consists of 100 images. 200 image sequences were prepared for each resolution. Figure 6(a) shows examples of the image sequence.

We evaluated the effectiveness of the proposed method by comparing the following three methods:
Proposed method: Recognition using a super-resolved image generated by using Eq. (2), proposed in this paper.
Comparative method 1: Recognition using a super-resolved image generated by using Eq. (1) that is used in the conventional super-resolution method [8].
Comparative method 2: Recognition using each image of an input image sequence directly.

To apply the super-resolution technique, we assumed that the degradation vector $\boldsymbol{b}_i$ is a Gaussian ($\sigma = 0.7$). The parameter α of the sigmoid function was set to 0.038, and $M' = 4M$. We used the QR Code Decode Library by Phytec as the decoder [10].

Recognition rate was used for evaluating the performance of the methods. In the comparative method 2, if at least one image was recognized correctly, the result was considered as a success. In the proposed and the comparative method 1, if the super-resolved image generated from an input image sequence was recognized correctly, the result was considered as a success.

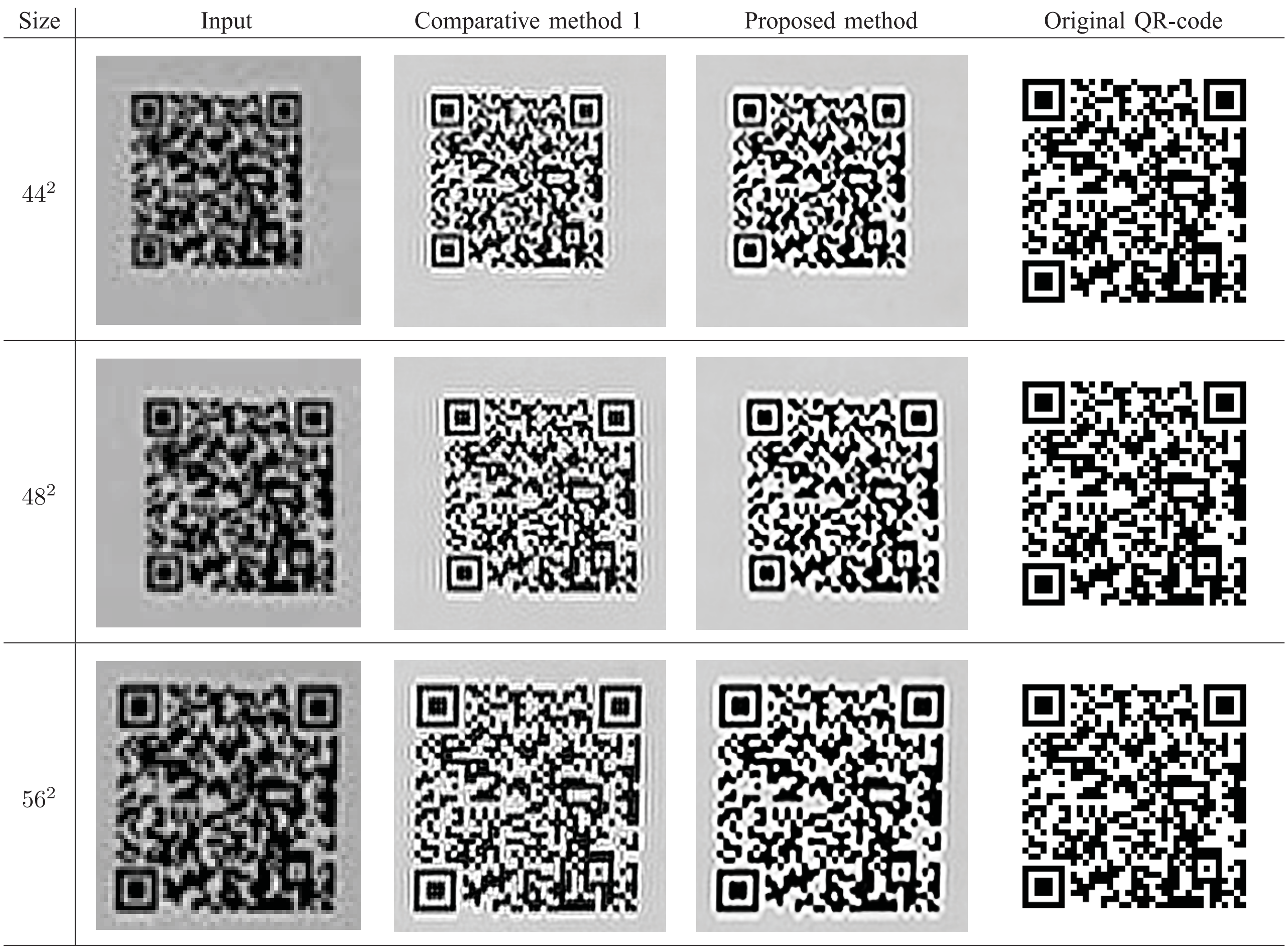


Figure 6. Examples of super-resolved images

A. Result

The examples of the generated super-resolved images are shown in Figs. 6 and 7. Figure 8 shows the recognition rates of the three methods. We can see that the comparative method 2 could not recognize correctly especially for the low resolution images ($44^2 \sim 50^2$). In contrast, the proposed method could recognize QR-codes from such low resolution images. In comparison with the comparative method 1 using the conventional super-resolution method, the recognition rate of the proposed method increased by 15.7% in average and 38.0% in maximum. The results show that the proposed method outperformed the other two methods especially for the low-resolution QR-code recognition.

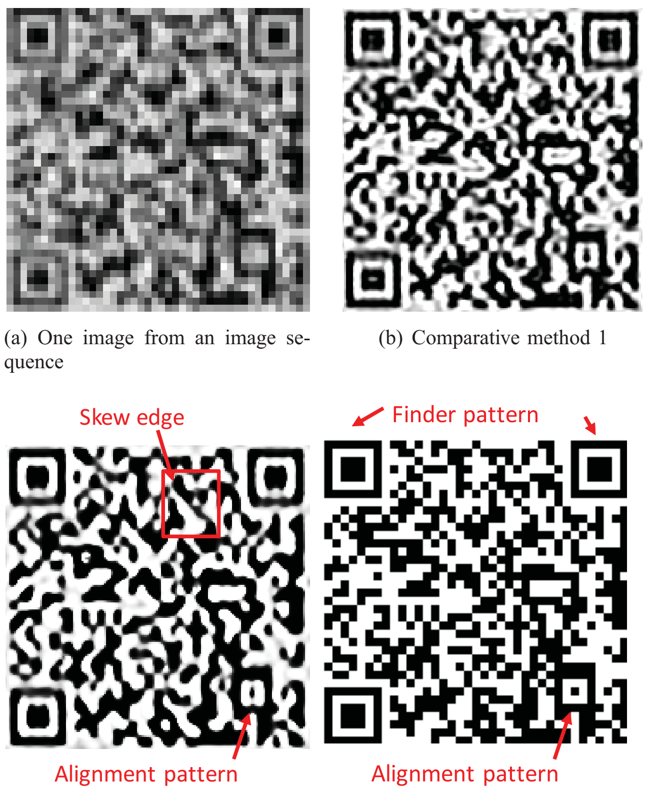
V. Disscussion

Figure 7(c) and (d) show the “Alignment pattern” and the “Finder pattern” that are special symbols and indispensable for QR-code recognition. The comparative method 1 often failed to detect them due to the blurred boundaries. Therefore, the recognition rate of the comparative method 1 became low. In contrast, these patterns were observed clearly in the super-resolved images by the proposed method.

As shown in Fig. 7(c), some skew edges were observed although a QR-code has only two orthogonal oriented edges. These edges may make the QR-code recognition difficult. To avoid this problem, we will use an additional property on the rectangularity of the QR-code in the future.

VI. Conclusion

In this paper, we proposed a recognition method for low resolution QR-codes applying a super-resolution technique. In the super-resolution process, the proposed method uses the property that QR-codes consist of a binary pattern only. Experimental results showed the effectiveness of the proposed method especially for recognizing low resolution QR-codes. Compared with a recognition method that uses a conventional super-resolution method, the recognition rate



(a) One image from an image sequence (b) Comparative method 1

(c) Proposed method (d) Original QR-code

Figure 7. Examples of generated images: 44^2 [pixels]

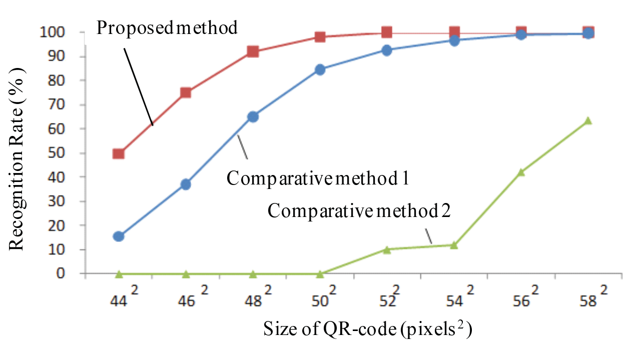


Figure 8. Recognition rates of low-resolution QR-codes.

of the proposed method increased by 15.7% in average and 38.0% in maximum.

Future work includes introduction of other properties of QR-codes, and integration of the recognition process and the super-resolution process.

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