QR Code Image Correction based on Corner Detection and Convex Hull Algorithm

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***Abstract*—Since the angular deviation produced when shooting a QR code image by a camera would cause geometric distortion of the QR code image, the traditional algorithm of QR code image correction would produce distortion. Therefore this paper puts forward the algorithm which combines corner detection with convex hull algorithm. Firstly, binaryzation of the collected QR code image with uneven light is obtained by the methods of local threshold and mathematical morphology. Next, the outline of the QR code and the dots on it are found and the distorted image is recovered by perspective collineation, according to the algorithm raised by this paper. Finally, experimental verification is made that the algorithm raised by this paper can correctly find the four apexes of QR code and achieves good effects of geometric correction. It will also significantly increase the recognition rate of seriously distorted QR code images.**

***Index Terms*—QR Code Image; Geometric Correction; Harris Corner Detection; Vertex Coordinates**

I. INTRODUCTION

As a technique of information storage, transmission and recognition with high volume, QR code has caught the attention of numerous countries around the world since its birth. Invented in 1994 by the Japanese company Denso, the technique not only possesses the common merits of other frequently-used two-dimensional codes, but also can make optimized encoding of information such as Chinese characters and images, and endow the information with features of high-speed reading and all-round recognition [1-4]. In result, the QR code gets extensive application in fields such as agricultural product tracing, food safety, credential recognition, transport and package, and electronic data interchange [5].

One frequently-used geometric correction method of QR code image is Hough transform. Hough transform requires that there is no interference of other straight lines around the QR code image when conducting line detection [6], otherwise there will be false detection. What's more, Hough transform is greatly effective only for image rotation, and it is unable to tackle distorted images [7-9]. In order to solve the problem of distorted QR code images, this paper puts forward the method that combines Harris corner detection with convex hull algorithm [10-14]. Using this method, a quadrilateral outline of QR code as well as its four vertex coordinates is obtained. Finally, the distorted QR code image is corrected by perspective collineation. In terms of algorithm that detects the four vertexes coordinates of QR code image, researchers from home and abroad have conducted a large amount of researches and have put forward many effective algorithms [15-17]. OHBUCHI E divides the central region into parts and takes the minimum of all the threshold values as the segmented threshold. Then he gets three apexes of the position detecting image and later gets the fourth apex. However, his threshold selecting method is easy to cause excessive segmentation and then the failure of decoding. However, the recognition rate is not high. A rapid barcode positioning method was proposed based on one-dimensional characteristic template, which gets boundary lines and vertex positions by conducting Hough transform on the barcode. Then it conducts control point transform, gets the images which only contain the barcode and then decodes. According to the appearance features of discrete curves, the local minimum appears when getting quadratic sums of k dots on the discrete curve towards Euclidean distance. Therefore the algorithm of minimum Euclidean distance from the angular points of QR codes to the four apexes of the outer rectangle was proposed. However, experiments show that when there is serious skewness of QR codes, other dots on the QR code outline are nearer from the apex of the outer rectangle outline. And this means false detection. Following the idea of getting convex and concave vertices of a random polygon according to the position relation between the several kinds of dots by geometric algorithm and straight lines, this paper proposes that the shortest distance appears from the four apexes of the quadrilateral outline of QR codes to the line that parallels with the quadrilateral's diagonal line. Experiments compare the two methods and show that the latter can detect the four apexes of QR codes more correctly. Finally, the distorted QR code image is recovered by perspective collineation. In addition, experiments of two-dimensional code reading show that the method raised in this paper effectively raises the reading rate of two-dimensional codes.

This paper makes innovations mainly in the following aspects:

Due to uneven light in the collecting environment, the brightness of QR code images is also uneven and it is difficult to get a virtual image display. So the images

doi:10.4304/jmm.8.6.662-668

need binaryzation of which the most important thing is to get the threshold. There is weakness of sauvola binaryzation method, so this paper makes some improvement on the method.

Under the circumstance that the traditional QR code image correction produces distorted images, this paper, on the basis of full analysis on corner detection and convex hull algorithm, makes use of the merits of the methods, combines them together and conducts binaryzation on the QR code images with uneven light by the methods of local threshold and mathematical morphology. Finally, by geometric correction, the recognition rate of QR code images is significantly increased. So this paper inventively puts forward the algorithm which combines corner detection with convex transform for QR code image correction.

In order to further prove the correctness and the effectiveness of the algorithm which combines corner detection with convex transform, detailed experiments are conducted. These experiments show that compared with similar algorithms, this method makes great improvement in the number of successful encoding and the accuracy rate of recognition so that it can make effective QR code image correction.

II. Proposed Scheme

In real life, due to uneven light in the collecting environment, the brightness of the QR code images is also uneven and it is difficult to get a virtual image display. Therefore the images need binaryzation of which the most important thing is to get the threshold.

A. Sauvola Adaptive Binaryzation on Texts

The computing method of sauvola adaptive binaryzation on texts is as follow:

$$T(x,y) = mean(x,y).\left[1 + k.(1 - \frac{E(x,y)}{R}\right] \quad (1)$$

The default for R is 128 and that for k is 0. 5. This method can effectively avoid the impact of spots and it is not sensitive to the number of k. However, the defaults do not fit for QR code images and there is often excessive segmentation which will disturb the correct reading of QR code images (Figure 1). There are also the problem of time consumption. Therefore proper numbers of R and k need to be found.

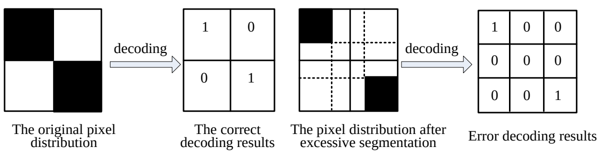


Figure 1. The weakness of sauvola binaryzation on texts

B. Improved QR Code Image Binaryzation

According to the encoding standard of QR code symbols, after masking processing, the proportion of dark module to light module is about 1: 1. This means that when QR code (except for the blank space) occupies the whole image, the percentages of pixel in foreground and background are roughly the same. Therefore, it is proper to set k at 0. 5. Experiments show that the number of R is related with the width of QR code, so the paper raise a method which roughly estimates the number of R according to the size of image.

L, symbolizing for the width of QR code, is defined as:

$$L = (18 + 4.V).d \quad (2)$$

V symbolizes the QR code versions from 1 to 40 and d symbolizes the module width. Supposing that QR code symbols (except for the blank space) occupy the whole input image, the proportion of module width to the whole image width is:

$$p = \frac{E}{L} = \frac{1}{18 + 4.N} \times 100\% \quad (3)$$

In most cases, the width of the position detecting image is the maximum width among QR code symbols (Figure 2). When the version is 1, the proportion of module width to the whole image width is:

$$p = \frac{7E}{L} = \frac{7}{18 + 4 \times 1} \times 100\% = \frac{1}{3} \times 100\% \quad (4)$$

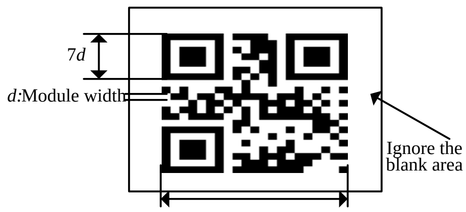


Figure 2. The QR code module

According to the formulas above, the estimated maximum of R is got:

$$R = D.P = \frac{1}{3} D \quad (5)$$

D symbolizes the maximum of the width and height of image.

When the order number of the version increases or the QR symbols does not occupy the whole image, the number of R will be less than a third of D. Therefore the estimated maximum of R can be used to estimate the optimum. After graying the original image, the binaryzation process of the method includes the following steps:

a. Ascertain the number of b, the window side length of the region, as well as the number of parameter R and k.

b. Define the two square w_1 and $w_{2.}$ w_1: from 1+b to image_height+b, and y from 1+b to image width+b. w_2: x from [x-b/2-1/2] to [x+b/2] ; y from [y-b/2-1/2] to [y+b/2].

c. Use black pixel to expand the original to [Image_width+2b], Image_height+2b].

d. As for the present pixel I (x, y) in the region W_2, use formula (6) and (7) to compute the average and standard deviation of it in the region W_2.

$$mean(x,y) = \frac{1}{b^2} \sum_{(x,y)^{\in w}} I(x,y) \quad (6)$$

$$s(x,y) = \sqrt{\frac{1}{b^2-1} \sum_{(x,y)\in w} (I(x,y) - mean(x,y))^2} \quad (7)$$

e. Use formula (1) to compute the present threshold T(x, y)

f. If the threshold of the present pixel is higher than the threshold T(x, y), set the pixel white, otherwise black.

g. Move to next pixel and repeat the steps above until all pixels of the image are computed.

h. Establish a new binary image in region $W_{1.}$

C. Corner Detection Method

After pre-disposition of graying, binarizing and morphological filtering the RGB image of the QR code, the pre-disposed QR code image is disposed on the basis of Harris corner detection and convex hull algorithm in order to the apexes and the outline of the image. The whole process is shown in Figure3.

1) Harris Corner Detection Method

The algorithm of Harris corner detection this paper adopts first needs to get a image block W∈f by getting a binarized two-dimensional code image f after pre-disposing, and translate x, y. S, the quadratic sum of the difference between the number of the image f in W and the translated image, is:

$$s_w(\Delta x, \Delta y) = \sum_{x_{i\in w}} \sum_{y_{i\in w}} (f(x_i - y_i) - f(x_j - \Delta x, r_i - \Delta r))^2 \quad (8)$$

Angular point will not be influenced by the aperture problem and it is highly responsive to x, y, $s_w(x, y)$. If making the first-order Taylor expansion approximation of the translated image, the image can be shown as:

$$f(x_i - \Delta x, y_i - \Delta y) \approx f(x_i, y_i) + \left[\frac{\partial e(x_i, y_j)}{\partial x}, \frac{\partial f(x_i, y_i)}{\partial y}\right] \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} \quad (9)$$

At this time, the minimum of s_w (x, y) has an analytic solution. Substituting the similar formula with formula (9) in formula (8) can get:

$$s(x,y) = [\Delta x, \Delta y] A_m(x,y) \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix}$$

The Harris matrix Aw(x, y) is the second derivative of s at the point(x, y)=(0, 0). And A is:

$$A(x,y) = \begin{bmatrix} \sum_{x_i\in w} \sum_{y_i\in w} \frac{\partial^2 f(x_i, y_i)}{\partial x^2} \\ \sum_{x_{i\in w}} \sum_{y_i\in e} \frac{\partial f(x_i, y_i)}{\partial x}, \frac{\partial^2 f(x_i, y_i)}{\partial y^2} \end{bmatrix}$$

Usually, an isotropy window such as Gaussian window is used, and its response is also of isotropy. Local structure matrix A symbolizes neighborhood and Harris matrix A is a positive semidefinite symmetrical matrix. Its main changing pattern corresponds to the partial in orthogonal direction, and is reflected by λ1 and λ2, the eigenvalues of matrix A. The two eigenvalues are both large and a slight move in any direction will cause a significant change of image f. At this time a corner is detected. Harris suggests that computing response function:

$$R9A) = \det(A) - k * trace^2(A)$$

It can avoid accurate eigenvalue computing. And det (A) is the determinant of local structure matrix A, trace (A) is the trace of matrix A, and k is the adjustable parameter with proper value range from 0. 04 to 0. 15. After Harris corner detection, all corners of QR code image are obtained and shown in Figure4.

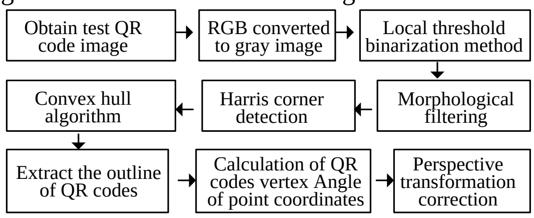
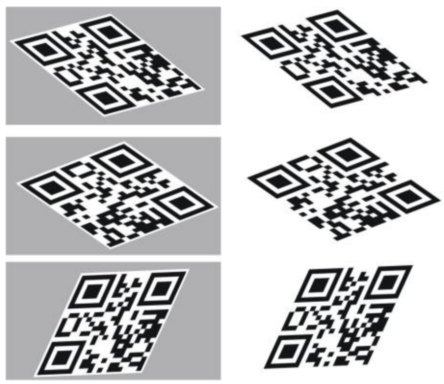


Figure 3. The process of the algorithm



(a) the original QR code (b) Harris corner detection

Figure 4. Harris corner detection

2) Convex Hull Algorithm

A region R is convex. When and only when random two dotsx1, x 2∈ R, the whole straight line portion x_1 x $_2$, which is defined by the line's end points x1, x 2, is inside the region R. The convex hull of a region is the minimum convex region which meets the requirements of R and H. Make the polygon of the convex hull waiting detection a simple polygon P= { v_1, v_2,. . . , v_n } and dispose the apexes according to this order. As for random three apexes x, y, z in the order, a directivity functionδcan be estimated.

δ (x, y, z) =1 if z is at the right side of the oriented line xy

δ (x, y, z) =0 if z is of collineation with the oriented line xy

δ (x, y, z) =- 1 if z is at the left side of the oriented line xy

Main data structure H is a collection of polygon apexes which has been disposed (deque). The present content of H shows part of the convex hulls of the polygon which have been disposed. And after the detection the convex hulls are contained in this data structure. Therefore H always symbolizes a closed polygon H={d_b, …d_t} and d_b points to the bottom of the list and d_t the top. And d_b and d_t always symbolize the apexes of a polygon's starting and terminal point.

The main idea of this algorithm is that the first three apexes A, B and C of the list P form a trangle(if they are not on the same line), and this trangle shows the convex hulls of the first three apexes. Then examine in this list whether next apex D in inside or outside of the current convex hull.

If D is inside the convex hull, then the current convex hull remains unchanged. If D is outside of the current convex hull, D must become a apex of a new convex hull. While for the shape of the current convex hull, no apexes, or one or several apexes must be eliminated from the current convex hull. Repeat this process on all rest apexes in list P. The outline of the distorted QR code image form a convex hull. Use Harris corner detection to get the corner of the QR code image and use convex hull algorithm to get the outer outline of the image which is shown in Figure 5.

Figure 5. Convex hull algorithm

3) The Algorithm to Compute the Four Vertex Coordinates of the QR Code Image

In real collecting process, the QR code can not avoid skewness, causing difficulties for later decoding. Therefore the distorted QR code must be corrected. First the four apexes of the QR code image must be obtained and then the skewness needs to be corrected by perspective collineation. In order to obtain the four apexes of the QR code image, Zhou Peide raises an idea. First, conduct edge detection using Canny operator, and scan the margin of the image including the image of margin information. Then scan the image of code margin image from its top in the way of scanning from the outside to inside. Stop scanning when encountering the first white dot and record the position of the white dot. In this way the four sampling points on the margin can be obtained. Conduct curve fitting on the four sampling points by the method of least squares and the approximate code margin can be obtained. Similarly, another three approximate code margins can be obtained by scanning the image from the bottom, left side and right side perspective. And the crossover point of two neighboring code margins is the apex of distorted code. This paper proposes that minimum Euclidean distance from the angular points of QR codes to the four apexes of the outer rectangle. However, experiments show that when there is serious skewness of QR codes, other dots on the QR code outline are nearer from the apex of the outer rectangle outline. And this means false detection. This paper gets convex and concave vertices of a random polygon according to the position relation between the several kinds of dots by geometric algorithm and straight lines and puts forward that the shortest distance appears from the four apexes of the quadrilateral outline of QR codes to the line that parallels with the quadrilateral's diagonal line. Concrete steps are as follow:

a. Graying and binarizing the QR code shoot by the camera.

b. Using the algorithm raised by this paper as well as Harris corner detection and convex hull algorithm to obtain the margin information of QR code image margins.

c. The way to read QR code image is height/width and set the skewness rate of quadrilateral outline as k_1, $k_1>0$ and k_1=height/wight. It should be guaranteed that $k_1 * k_2 = -1$ so as to compute k_2.

d. Using the skewness rate obtained by step(3) to get four straight lines L_1, L_2, L_3 and L_4 of which the skewness rates are k_1, $-1/k_1$, k_1 and $-1/k_1$ respectively. The four straight lines are near the four apexes of the QR code respectively as shown in Figure6.

Figure 6. The division of straight lines at four corners which parallel with the quadrilateral's diagonal line

Set the distances from a random point on the QR code margin to L_1, L_2, L_3 and L_4 as d_1, d_2, d_3 and d_4 respectively and then get:

$$d_1 = |y_1 * u + v - y_1 + 1| / \sqrt{1 + y_1^2}$$

$$d_2 = |u / y_1 - v + height| / \sqrt{1 + 1/(-y_1)^2}$$

$$d_3 = |u / y_1 - v - width / y_1| / \sqrt{1 + 1/*(-y_1)^2}$$

$$d_4 = |k_1| * u + v - height - y_1 * width / \sqrt{1 + y_1^2}$$

(u, v) is the coordinate value of a random point on the QR code margin; and(width, height) is the size of the QR code image after graying.

Substitute the point on the QR code image margin in the above formula. When d_1, d_2, d_3 and d_4 reach their minimums, record the coordinate values at that time and the records are the coordinates of the four apexes of the QR code as shown in Figure 7.

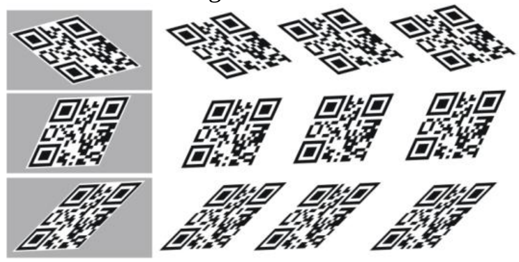


Figure 7. The compare of several algorithms

Experimental results show that the corner detection algorithm will produce false detection of different degrees when detecting QR code image with a large deflection ancle. Compare shows that the algorithm raised by this paper can better detect the QR code corners.

D. Geometric Correction

When the surface of the digital camera does not parallel with that of object of which the image will be shoot, the collected QR code image will get perspective distortion. The distorted QR code image basically maintains the features of irregular quadrilaterals. A method dealing with perspective distortion raised by Shang Zhenhong is to demonstrate the space relocation of pixel by “linking points”. These points are subsets of the pixel and their positions in the image can be obtained. The quadrilateral region can be obtained by conducting convex hull algorithm on the image in Figure3 and the apexes of the quadrilateral are the linking points perspectively. Apexes of the quadrilateral can be set as A, B, C and D in an order of the upper left, the lower left, the lower right and the upper right. And they correspond to the four apexes of the square QR code image: the upper left (A'), the lower left (B'), the lower right(C ')and the upper right (D'). Set (x, y) as the coordinate of the QR code on the original image, (u , v)as the normal coordinate after plane projection transformation, and a - h as the eight parameters in the transforming formula waiting to be solved. The parameter solutions can be obtained by at least transforming four groups of coordinates and substituting them in to the equation.

$$x = \frac{au + bv + c}{gu + hv + 1}$$

$$y = \frac{du + ev + f}{gu + hv + 1}$$

After simplification what can be obtained is:

$$x = au + bv + f - guv - hbx$$

$$y = du + fv + x - guy - hby$$

Solve the eight parameters from a to h, get the coordinates of the upper left, the upper right, the lower right and the lower left points of the QR code and substitute them in the above formula:

$$\begin{bmatrix} v_o & v_o & 1 & 0 & 0 & 0 & -u_0x_0 & -v_0x_0 \\ v_1 & u_2 & 1 & 0 & 0 & 0 & -u_1x_1 & -v_1x_1 \\ u_2 & v_2 & 1 & 0 & 0 & 0 & -u_2v_2 & -v_2u_2 \\ u_3 & v_3 & 1 & 0 & 0 & 0 & -u_3v_3 & -v_3u_3 \\ 0 & 0 & 0 & u_0 & v_0 & 1 & -u_0v_0 & -v_0u_0 \\ 0 & 0 & 0 & u_1 & v_1 & 1 & -u_1v_1 & -v_1u_1 \\ 0 & 0 & 0 & u_2 & v_2 & 1 & -u_2v_2 & -v_2u_2 \\ 0 & 0 & 0 & u_3 & v_3 & 1 & -u_3v_3 & -v_3u_3 \end{bmatrix} * \begin{bmatrix} a \\ b \\ c \\ d \\ e \\ f \\ g \\ h \end{bmatrix} = \begin{bmatrix} u_0 \\ u_1 \\ u_2 \\ u_3 \\ v_1 \\ v_2 \\ v_3 \\ v_4 \end{bmatrix} \quad (10)$$

The coordinates of four apexes after code positioning process, correspond to the coordinates of the square whose shape is pre-set after plane projection transformation. Set the height and width of the transformed square as W, average of the previous four side length with unchanged central point and the corresponding points of the four coordinates can be obtained: the upper left (0, 0), the upper right(W, 0), the lower right (W, W) and the lower left (0, W). Substitute them in formula (10) and the solutions of parameters a-h can be obtained:

$$a = \frac{(1+w_e)y_1 - y_0}{w}$$

$$b = \frac{(1+w_e)y_2 = y_0}{w}$$

$$c = y_0$$

$$d = \frac{(1+w_e)x_1 - x_0}{w}$$

$$e = \frac{(1+w_e)x_3 - y_0}{w}$$

$$f = x_o$$

$$g = \frac{(y_3 - x_1)(y_1 - x_0) - (x_2 - x_0)(y_3 - y_2)}{w\left[(x_3 - y_2)(y_3 - y_2) - (x_2 - x_1)(y_2 - y_1)\right]}$$

III. Experimental Results

In practice, QR codes are frequently stick onto the surfaces of plastic bags, plastic bottles and paper and it is impossible to shoot QR codes from the front accurately by a camera. Therefore QR codes are easy to get distorted as rhombus or trapezoid. In order to conduct analysis of geometric correction on distorted QR code images, the testing image is collected by a Panasonnic digital camera in a laboratory whose size is 2592*1944 pixels. Then QRecognition-vs90 is used for test as a QR code recognition software. It is a QR code recognition software base on PC and developed by OPENCV whose copyright belongs to JMA (Japan Medical Association). This software can achieve good recognition effects for QR code images shoot from the front. However its recognition rate for QR code images with a deflection ancle more than 17°and distorted images. This paper mainly examines the correction effect of QR code images by softwares. In order to decrease subjective impact, images are shoot from the diagonal direction and the side in an order from small inclined angles to large ones. 200 testing images are chosen for each angle. Due to high resolution ratio and the large amount of testing images, testing images can be changed to 320*240 pixels by bilinear interpolation. The testing platform is MATLAB 2010 of the Windows XP operating system and the hardware configuration is AMD dual-core and 2GB internal memory. Then testing images are disposed by position detection pattern and the algorithm raised by this paper and the results are compared.

The experimental results of the geometric correction algorithm raised by this paper are shown in Figure 8.

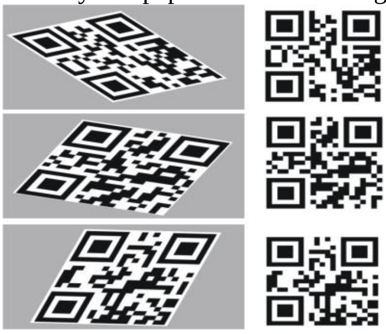


Figure 8. Experimental results of geometric correction algorithm of QR code image

TABLE I. STATISTICS OF RECOGNITION RESULTS OF QR CODE IMAGES

Recognition software	Deflection angle	Number of samples	Number of image recognition before detection	Number of image recognition after detection	Increase of recognition rate
QRecognit	Less than 17^0	204	189	198	4. 65
Ion-vs90	More than 17^0	204	35	169	68. 62%

TABLE II. STATISTICS OF RECOGNITION RATES OF SIMILAR ALGORITHMS

algorithm	Number of examined images	Number of decoding	Accuracy rate
LiJun's algorithm	204	145	71. 8%
ZhouPeide's algorithm	204	158	79.1%
Algorithm raised by this paper	204	179	87. 9%

QR Code recognition softwares are used to examine the increase in recognition rate after distortion correction. Before QR code recognition, it needs to fix the position and get the outline first to find the region waiting to be recognized. The algorithms of current QR code recognition softwares such as QRCode and QRreader can recognize distorted QR code images. Using the algorithm raised by this paper as well as QRecognition-vs90 can get examination results in Figure1. After correction, from the result of table 1, we can see that in the condition that the number of samples is 200, the number of identification images before correction respectively is 187 and 32 and after correction the number is 196 and 167, whose recognition rates respectively increase by 4. 5% and 67. 5%. Therefore, the algorithm in this paper can better improve the recognition rate of QR code recognition software. Table 2 presents the statics of Li Jun's algorithm, Zhou Peide's algorithm and the algorithm in this paper for 200 pictures of QR code image recognition rate. In the condition that number of test sample is 200, the number of LI Jun's decoders is 144; Zhou Peide is 156 and the algorithm in this paper is 177. For the accuracy, Li Jun is 72%; Zhou Peide is 78% and the algorithm in this paper is 88. 5%. This algorithm combines the improved corner detection algorithm with the convex hull algorithm and the size of QR code image is height/width. The slope of quadrilateral shape is set for k1 and k1 > 0. We set that k1 = height/width and k1 * k = 1, and then k2 is calculated, by this paper achieves obvious advance in successful decoding rate than Li Jun's and Zhou Peijun's algorithms.

IV. CONCLUSION

When shooting QR code images under natural conditions, the deviation of shooting angle can cause geometric distortion of the shoot QR code image and assert great impact on the recognition of QR codes. This paper adopts the algorithm which combines Harris corner detection with convex hull algorithm to get the outline of the outer quadrilateral of the QR code, then finds the four apexes of the QR code image borrowing the geometric algorithm, and finally corrects the QR code image by perspective collineation. Results show that this algorithm can correctly find the four apexes of the QR code and achieve good effects of geometric correction, significantly raising the recognition rate of the seriously distorted QR code image. Due to the fairly complex realistic environment, there are still some problems of this algorithm. In real life, QR codes are usually printed on the surface of goods such as cylindrical water bottles, causing cambered distortion. Robustness in circumstances of serious distortion is not strong and it needs further studies.

REFERENCES

[1] Kasman Suhairi, Ford Lumban Gaol, The Measurement of Optimization Performance of Managed Service Division with ITIL Framework using Statistical Process Control. *Journal of Networks*, Vol 8, No 3 (2013), pp. 518-529
[2] Guang Yan, Zhu Yue-Fei, Gu Chun-Xiang, Fei Jin-long, He Xin-Zheng, A Framework for Automated Security Proof and its Application to OAEP. *Journal of Networks*, Vol 8, No 3 (2013), pp. 552-558
[3] R. Berangi, S. Saleem, M. Faulkner, et al. TDD cognitive radio femtocell network (CRFN) operation in FDD downlink spectrum. *IEEE, 22nd International Symposium on Personal, Indoor and Mobile Radio Communications*, 2011 pp. 482-486
[4] W. Ahmed, J. Gao, S. Saleem, et al. An access technique for secondary network in downlink channels. *IEEE, 22nd International Symposium on Personal, Indoor and Mobile Radio Communications*, 2011 pp. 423-427
[5] D. L. Sun, X. N. Zhu, Z. M. Zeng, et al. Downlink power control in cognitive femtocell networks. *IEEE., International conference on wireless communications and signal processing*, 2011 pp. 1-5
[6] Muhammad J. Mirza, Nadeem Anjum. Association of Moving Objects Across Visual Sensor Networks. *Journal of Multimedia*, Vol 7, No 1 (2012), pp. 2-8
[7] Haiping Huang, Hao Chen, Ruchuan Wang, Qian Mao, Renyuan Cheng. (t, n) Secret Sharing Scheme Based on Cylinder Model in Wireless Sensor Networks. *Journal of Networks*, Vol 7, No 7 (2012), pp. 1009-1016
[8] Xin Huang, Xiao Ma, Bangdao Chen, Andrew Markham, Qinghua Wang, Andrew William Roscoe. Human Interactive Secure ID Management in Body Sensor Networks. *Journal of Networks*, Vol 7, No 9 (2012), pp. 1400-1406
[9] Muhammad J. Mirza, Nadeem Anjum. Association of Moving Objects across Visual Sensor Networks. *Journal of Multimedia*, Vol 7, No 1 (2012), pp. 2-8
[10] Zhao Liangduan, Zhiyong Yuan, Xiangyun Liao, Weixin Si, Jianhui Zhao. 3D Tracking and Positioning of Surgical Instruments in Virtual Surgery Simulation. *Journal of Multimedia*, Vol 6, No 6 (2011), pp. 502-509
[11] Kuo-Feng Huang, Shih-Jung Wu, Real-time-service-based Distributed Scheduling Scheme for IEEE 802. 16j Networks. *Journal of Networks*, Vol 8, No 3 (2013), pp. 513-517

[12] N. Omidvar, B. H. Khalaj. A game theoretic approach for power allocation in the downlink of cognitive radio networks. *IEEE*., 16th CAMAD, 2011: pp. 158-162
[13] D. Xu, Z. Y. Feng, Y. Z. Li, et al. Fair Channel allocation and power control for uplink and downlink cognitive radio networks. *IEEE., Workshop on mobile computing and emerging communication networks*, 2011: pp. 591-596
[14] W. Q. Yao, Y. Wang, T. Wang. Joint optimization for downlink resource allocation in cognitive radio cellular networks. *IEEE, 8th Annual IEEE consumer communications and networking conference*, 2011: pp. 664-668
[15] K. Ruttik, K. Koufos, R. Janttir. Model for computing aggregate interference from secondary cellular network in presence of correlated shadow fading. *IEEE, 22nd International symposium on personal, indoor and mobile radio communications*, 2011: pp. 433-437
[16] J. Naereddine, J. Riihijarvi, P. Mahonen. Transmit power control for secondary use in environments with correlated shadowing. *IEEE, ICC2011 Proceedings*, 2011 pp. 1-6
[17] S. H. Tang, M. C. Chen, Y. S. Sun, et al. A spectral efficient and fair user-centric spectrum allocation approach for downlink transmissions. *IEEE., Globecom*., 2011: 1-6
[18] Wright J, Yang A, Ganesh A, et al., "Robust face recognition via sparse representation", *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 31, no. 2, pp. 210-227, 2009.
[19] A. Wagner, J. Wright, A. Ganesh, Z. Zhou, and Y. Ma, "Toward a practical face recognition: Robust registration and illumination via sparse representation", *In Proceeding(s) of Conference on Computer Vision and Pattern Recognition (CVPR)*, pp. 597-604, 2009.
[20] D. Donoho, "Compressed Sensing", *IEEE Transactions on Information Theory*, vol. 52, pp. 1289-1306, 2006.
[21] Q. Zhang, B. Li, "Discriminative K-SVD for dictionary learning in face recognition", *Proceeding(s) of Conference on Computer Vision and Pattern Recognition (CVPR)*, pp. 2691-2698, 2010.
[22] Mao X. Nguyen, Quang M. Le, Vu Pham, Trung Tran, Bac H. Le, "Multi-scale Sparse Representation for Robust Face Recognition", *Proceeding(s) of Conference on Knowledge and Systems Engineering (KSE)*, pp. 195-199, 2011.