Design of Anti-Distortion Two-Dimensional Code on Prism and Cylinder Combination Surface based on Pre-Stretching

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Abstract. Two-dimensional code has shown its impressive performance on mobile payment and advertising marketing. To ensure that the two-dimensional code is correctly identified by recognition devices, the traditional two-dimensional code must be attached to the surface of plane. However, if the code attached to the surface of cylinder or prism carrier, the image of the normal two-dimensional code will be distortion because of image projection, which will lead to identification problem. To this end, we propose a novel approach of design and identification of anti-distortion two-dimensional code on prism and cylinder combination surface based on pre-stretching, to address the challenge of identifying a two-dimensional code on prism and cylinder combination carrier. According to the spatial geometric relation of the two-dimensional code carrier, pre-stretching the normal two-dimensional code image via inverse mapping to obtain the pre-deformed two-dimensional code that will be printed and then pasted on the surface of the carrier. Specifically, the image of the pre-stretched two-dimensional code in the projection plane of the acquisition device is just as the normal two-dimensional code, which will be correctly identified. Experimental results show that the two-dimensional code after pre-stretching could be identified by normal recognition devices.

1. Introduction
With the continuous development of economy and computer technology, people have higher requirements for the quality of goods, and the requirement of improving quality supervision has become the consensus of people. In the past, every kind of commodity affixed with a label, but it has been unable to meet our needs. "One thing, one code" has become an urgent need. With the rapid development of mobile Internet, smart phones and 4G networks, due to its high information content and low cost, two-dimensional code has sprang up in goods labelling. It can express information in both longitudinal and transverse directions, and has the characteristics of large storage capacity, high confidentiality, high tracking ability, strong resistance to damage, high redundancy and low cost and other characteristics [1]. The two-dimensional code expands the encoding capacity, and the scope of the code expanded to the number, letters, Chinese, pictures and sound. What’s more, it can quickly correct the error code word, and the process of use of two-dimensional code could be independent of the database [2]. The application of two-dimensional code is becoming more and more abundant [3].

The two-dimensional code not only brings us convenience, but also brings a problem. In order to ensure the correct recognition of two-dimensional code, the placement of two-dimensional code is limited by certain conditions, i.e. the two-dimensional code should be printed on flat or nearly flat objects or displayed on flat screen. However, the small size commodities (such as pill bottles, injection
bottles, cosmetic containers, beverage bottles, handicrafts, daily necessities, etc.) have different surface shapes and sizes, such as spherical, cylindrical, conical, and cylindrical prism combination shape, etc. Direct paste two-dimensional code on these non-flat surfaces will inevitably lead to distortion, and the conventional identification equipment (such as cell phones) can’t identify the two-dimensional code, which limits the scope of the application of two-dimensional code and brings great difficulties to product quality supervision. Distorted two-dimensional code is shown in Figure 1.

![Figure 1. Distorted two-dimensional code](image)

Inspired by signal pre-stretching to counteract signal distortions in signal processing ([4] [5] [6]), we apply pre-stretching to two-dimensional code recognition. Based on the space geometry of two-dimensional code dependent on the carrier, used a pre-stretching algorithm to amplify or deform the normal QR code. When the distorted QR code is pasted on the surface of a cylindrical prism combination object, when capture a two-dimensional code image using a CCD reading device (such as a cell phone), the two-dimensional code image on the imaging projection surface is compressed into a normal two-dimensional code. Any decoding software can scan and decode at the center of the two-dimensional code. Furthermore, it will improve the scope of application of two-dimensional code.

The rest paper is presented as follows. In section II, we review some related work about how to tackle the above problem. In section III, we introduce our Pre-stretching algorithm in detail. And in section IV, we show the experiment design and results. Finally, section V concludes the paper.

2. RELATED WORK

2.1. Three-dimensional Perspective Transformation

In [7], it proposed a two-dimensional code recognition method based on three-dimensional perspective transformation, which can effectively identify the QR code printed on cylindrical surfaces such as beverage bottles. In this method, the key word of the image contour is detected to determine the location of the back-to-back glyph. On this basis, the key contour of the bar code is selected and Huff's transform is performed to extract the information of the perspective ellipse on the cylindrical surface. Combined with the parameters of perspective ellipse and three-dimensional perspective transformation, the transformation matrix of cylindrical noodle barcode pixels mapping directly from two-dimensional image plane to three-dimensional image space is constructed effectively and the QR code target printed on plane or cylindrical surface is reconstructed. The experimental results show that the algorithm has high accuracy for recognizing plane or cylinder QR bar codes.
2.2. Projection Algorithm

[8] proposed a two-dimensional barcode recognition algorithm based on projection algorithm, and studied the algorithm of 2D barcode segmentation and recognition by taking PDF417 barcode as an example. Firstly, according to the Hough transform, the barcode on the image is located, and the barcode is rotated to the horizontal using bilinear interpolation. Then the image of a single code word symbol is located in the barcode. Finally, the projection algorithm is used to identify the single code word symbol. The proposed projection algorithm can effectively remove the impact of several common image noise on bar code recognition and improve the recognition rate of bar codes. The experimental results fully show that the algorithm has good performance and meets the requirements of practical application.

2.3. Correlation Matching

Related scholars have also proposed a two-dimensional code recognition method based on correlation matching [9]. The process of the method is as follows: The improved adaptive threshold method based on surface fitting is used to segment the image. Hough transform and control point transform are used to correct the geometric distortions of the image. The template is used to match the two-dimensional code, and the sample grid is obtained by threshold the coherence coefficient. Experiments show that the algorithm can effectively improve the QR code recognition efficiency and effectiveness.

2.4. Correcting Parameters

[10] proposed a method of correcting and recognizing cylinder two-dimensional codes using cylinder parameters to solve the problem of identification when the QR code was printed on a cylindrical joint of a book. When collecting the QR code printed on the cylinder surface, due to distortion of the surface, a serious distortion occurs. The acquired two-dimensional code is no longer a rectangle, so that the two-dimensional code can’t be decoded. In this method, the three-dimensional perspective relationship is obtained by parameterizing the cylindrical model algorithm to correct the distorted two-dimensional code to obtain approximate standard two-dimensional code, and finally obtain the two-dimensional code information. Experimental results show that the algorithm has high accuracy for recognizing cylindrical QR bar codes.

2.5. Conic Segmentation

In [11], it proposed a QR code correction algorithm based on conic segmentation. When the QR code is skewed on the cylinder and we capture a QR code image, the QR code in this image is not the expected square which presented as a rectangular QR code. The QR code becomes distorted due to a problem with the camera acquiring the image mode, which distorts the image of the original QR code and Cause QR code decoding failed.

After observation of the QR code, the author found that the QR code structure is divided into horizontal and vertical straight lines that clearly divide the QR image into black and white square matrices of a block. These straight lines clearly divide the QR image into blocks of black and white square matrices that are distorted and curved as they are attached to the cylinder. The basic concept of QR code image correction is to fit these curves into a conic Model, then use a conic to segment the black and white blocks of the cylinder QR code image, and then copy each of the distorted black and white blocks to the corresponding position in the blank plot. The algorithm first uses Sobel edge detection to find the edge points, sets the model of the conic curve and uses the least square error solution to do the conic curve fitting, then the fitted conic curve cuts the black and white blocks distorted in the whole QR image, Finally, the corresponding position in the blank image is filled with the color of the distorted block. After several experiments, the above method can improve the recognition rate of the QR code.

In the above research works, although these algorithms have a good presentation in decoding, it is still idealized, since these methods place the correction part in the decoding stage, which results in slow decoding. To use these algorithms, the existing QR code decoding software must be modified to
have complicated functions and how many types of correction functional modules are required. These kinds of function modules have a huge workload, and it is almost impossible to deploy these modules to a CCD image recognition device such as a mobile phone.

3. DESIGN PRINCIPLES AND CONTENT

In everyday life, the two-dimensional code we have seen is usually printed or displayed at the approximate plane of the carrier. The two-dimensional code image we collect through the image acquisition device is a flat two-dimensional code image, and it can be decoded by the current two-dimensional code decoding device. However, when the carrier is a cylinder or a prism, the two-dimensional code image we collect through the image acquisition device will occur nonlinear deformation. If the two-dimensional code is small compared with the cylindrical prism combination surface, the two-dimensional code image can still be decoded by decoding software. But in other cases, the large deformation on both sides of the two-dimensional code makes the two-dimensional code can’t be decoded by decoding software. Then the existing decoding software needs to be redesigned to decode it. According to the problem described above, a method of design and identification of anti-distortion two-dimensional code on cylindrical prism combination surface based on pre-stretching is proposed. The pre-stretching is a kind of non-linear stretching which based on the relationship between the shape of two-dimensional code carrier surface and the two-dimensional code image. Put the deformed two-dimensional code image on the surface of the carrier. Then, the current two-dimensional code image is collected by the image acquisition device. Because the effect of projection compression counteracts the effect of pre-stretching, the projection plane is almost the same as the normal two-dimensional code. Because the pre-stretching is start at the center line of the normal two-dimensional code, the deformed two-dimensional code is centrosymmetric. When the image is collected, the image acquisition device need to be placed at the center of the two-dimensional code. Flow chart of specific design is shown in Figure 2, and the three-dimensional map of the cylindrical prism combination is shown in Figure 3.

![Flow chart of specific design](image-url)

**Figure 2.** Flow chart of specific design
3.1. Geometry Relation of cylindrical prism combination Vector Projection

According to the geometric mapping relationship, the height of the two-dimensional code remains unchanged in the pre-stretching, i.e. the image does not produce telescopic deformation in the longitudinal direction.

Therefore, it is only necessary to consider a longitudinal carrier of equal height to the two-dimensional code image. As shown in Figure 4, the carrier from O to O’ height is cut into thin slices with unit thickness of pixel, the number of sheets is h (in pixels). As shown in Figure 5, \( l_{HE} \) is the width of the two-dimensional code. In other word, \( l_{HE} \) can be used to represent the row pixels of the two-dimensional code image. According to the relational mapping, \( l_{HG} + l_{GF} + l_{FE} \) are the row of pixels corresponding to \( l_{HE} \) on the combination carrier, i.e. \( l_{HG} + l_{GF} + l_{FE} \) represents the row pixels of the deformed two-dimensional code image. According to the above principle, the deformed image can be obtained by following four steps:

Step 1: Set the proportion of two-dimensional code images in three decent faces i.e. \( l_{AB}, l_{BC}, l_{CD} \) the proportion can be set freely.

Step 2: According to the known two-dimensional code size and carrier diameter, edge length and other information, the length of \( l_{HG}, l_{GF}, l_{FE} \) can be calculated. The size of the two-dimensional code after deformation can be determined. Then select the tangent plane of the carrier which is shown in Figure 5 or Figure 6 (special case), and the next step is calculated as follows:
\[ l_{B'O} = \frac{l_{BC}}{2} = \frac{l_{AD} - l_{AB} - l_{CD}}{2} \quad (1) \]

\[ \theta = \arcsin\left(\frac{l_{B'O}}{r}\right) \quad (2) \]

\[ l_{GO'} = r \cdot \theta, l_{GF} = 2 \cdot l_{GO'} \quad (3) \]

\[ \beta = x, \alpha = y \quad (4) \]

\[ l_{HG} = \frac{l_{AB}}{\sin(\beta)}, l_{FE} = \frac{l_{CD}}{\sin(\beta)} \quad (5) \]

Step 3: Suppose the points \( x_1, x_2 \) are any two points on \( l_{GF}, l_{FE} \) respectively. \( y_1, y_2 \) are the mapping point of \( x_1, x_2 \). The length of \( l_{Gx_1} \) map on the two-dimensional code image is \( l_{By_1} \). And the length of \( l_{Fx_2} \) map on the two-dimensional code image is \( l_{Cy_2} \).

When the point \( x_1 \) moves to the point \( o' \), the relationship among the arc length \( l_{Gx_1} \), the center angle \( \gamma \) (radian system) and \( l_{By_1} \) is as follows:

\[ l_{x_1O'} = l_{GO'} - l_{Gx_1} \quad (6) \]

\[ \gamma = \frac{l_{x_1O'}}{r} (r \text{ represents the radius of circle}) \quad (7) \]

\[ l_{0''O} = r \sin(\gamma) \quad (8) \]

\[ l_{B'O''} = l_{B'O} - l_{0''O} \quad (9) \]

So the mapping arc of the row pixel \( B'O'' \) can be obtained.

When the \( x_2 \) point moves to the \( E \) point, the relationship among the arc length \( l_{Fx_2} \), the angle \( \beta \) (radian system) and \( l_{Cy_2} \) is as follows:

\[ l_{Cy_2} = l_{Fx_2} \cdot \sin(\beta) \quad (10) \]

From the above relation, it can see that when the \( x_1 \) point moves right along the \( l_{x_1O'} \) to the center \( O \) point, in order to obtain the pixel \( y_1 \) and \( y_2 \) of the pixel mapping of the row code of the corresponding original 2D code, only need to get the length of the mapped \( l_{Gx_1} \) and the length of the corresponding length \( l_{By_1} \). When the point \( x_2 \) moves right along \( l_{EF} \), in order to obtain the pixels of the pixel mapping of the corresponding two-dimensional code, only need to obtain the length mapped and the length of the corresponding original image.

Step 4: Through mapping from left to right in the normal two-dimensional code row-by-row, can get the unfold drawings of pre-stretched two-dimensional code after traverse the entire two-dimensional code image.

### 3.2. Process of Pre-stretching

For the application requirements, take the example of a carrier which the circle radius is 8cm and the both sides of the edges are 2cm special cases, and the two-dimensional code image is 10cm. First input the standard two-dimensional code image and obtain the number of rows \( \text{carrierRows} \), the number of columns \( \text{carrierCols} \). Once the image printed on the carrier, the number of rows does not change. The algorithm is as follows:

Step 1: According to formula (1) to (6), the row and column prime numbers of each part of the two-dimensional code image after deformation is obtained, and the concrete solution are as follows: \( l \) represents distance, \( L \) represents size of pixels

\[ L_{AB} = L_{CD} = \frac{2}{10} \cdot \text{carrierCols} \quad (11) \]

\[ L_{BC} = \text{carrierCols} - L_{AB} - L_{CD} \quad (12) \]
\[ L_{B'O} = \frac{l_{AD} - l_{AB} - l_{CD}}{2} \]  

(13)  

\[ \theta = \arcsin \left( \frac{l_{B'O}}{r} \right) \]  

(14)  

\[ \beta = \frac{\pi}{2} - \theta \]  

(15)  

\[ L_{HG} = L_{FE} = L_{AB} \cdot \sin(\beta) \]  

(16)  

\[ L_T = L_{B'O} \cdot \frac{r}{l_{B'O}} = \frac{l_{BC} \cdot r}{2 \cdot l_{B'O}} \]  

(17)  

\[ L_{GF} = 2 \cdot L_T \cdot \theta \]  

(18)

Step 2: The axis of the two-dimensional code image is located at the center O of each slice, \( l_{HG} + l_{GF} + l_{FE} \) are the row of pixels in the two-dimensional code. Correspond with the original pixels one-to-one by traversing each pixel. The left edge traversing from left to right one by one, i.e. the left edge start at H point and end with G point. H point corresponds to the original A point pixel, G point corresponding to the original B point pixels, the left traversal starting from A point, end with G point.

Step 3: When traversing the cylinder, the angle changes constantly. Divided the cylindrical prism combination part into two parts from the O point. Consider the case of traversing the left semicircle \( l_{GO'} \). Suppose the image traversal moves \( V_y \) on the left semicircle \( l_{GO'} \), then the corresponding location of the carrier is \( L_{AB} + L_T \cdot \sin \left( \frac{l_{GO'} - V_y}{L_T} \right) \) (consider left edge), left traversal end with point \( O' \).

Step 4: When traversing the right edge, start at F point and end with E point, F point corresponds to the pixel of C point, and E point corresponds to the pixel of D point. The left edge algorithm is the same as the right edge.

Step 5: All the cross section of the carrier is the same, so the number of pixels in a row of the two-dimensional after deformation unchanged. Through the calculation of the original two-dimensional code line by line, the deformed two-dimensional code image can be obtained (shown in Figure 6).

4. SOFTWARE IMPLEMENTATION AND SUMMARY

According to the above principle, the method of design and identification of anti-distortion two-dimensional code on cylindrical prism combination surface based on pre-stretching can be achieved by software. Specific steps are as follows.

Firstly, open the normal QR Code which will be processed.

Secondly, obtain the length of the image, the length of the cylinder diameter, edges length on both sides, angles degree on both sides.

Thirdly, pre-stretch the normal QR Code and save the processed image. Then the pre-stretching QR Code picture is obtained as shown in Figure 7.
Assume the diameter of the cylinder is 8 cm, and the width and height of the normal QR Code is 10 cm. Both edge are 2 cm and the left angle is 60 degrees while the right is 30 degree. At last, we can get the pre-stretching QR Code.

We get the pre-stretching QR Code by the above algorithm as shown in Figure 8. This picture is printed on the surface of a cylindrical prism combination. Getting the QR Code image through the image acquisition device and then we can get the following image shown in Figure 9.

In the end, the above image is identified by the decoding software and we can find out the following: When the normal QR Code print is printed on the surface of cylindrical prism combination, the decoding device failed to identify image because the image is impressed. The pre-stretching QR Code can counteract the deformation of cylindrical prism combination surface, so the decoding device can successfully identify image. This method of producing pre-stretching QR Code can increase the application occasions of QR Code.
5. Conclusions
This paper has proposed a pre-stretching anti-distortion two-dimensional code. Compared with the existing methods, our method does not need to modify the two-dimensional code recognition software, and recognition is fast and more efficient. Experimental results show that the two-dimensional code after pre-stretching could be identified by normal recognition devices.

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