A Technique for Printed 2-D Barcode Inspection

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Abstract— **This paper investigates a technique for printed 2-D barcode inspection. The combination of NCC template matching with average pixel weight method is investigated. The template matching is of necessary for barcode locating. However its matching score can be further used for inspection, but only for the finder pattern of the barcode. Average pixel weight, on another hand, can be used for both finder pattern and data cells inspection but the accurate cell position is needed. For data cell inspection we used the number of cells lie in a particular range of average pixel weight as a decision criteria.**

I. INTRODUCTION

The increase in machine vision and inspection has resulted in great productivity improvement. Product ID detection is widely used; from the manufacturing phase to end user or customer. Barcode is one mean among several available ID objects. Despite its complexity, a 2-D barcode can accommodate more information when compared to a classical 1-D barcode. Moreover its physical size is smaller. In practical application a single barcode may be read many times by many different operators and machines, the quality of the barcode is therefore of importance. The printed barcode must be clear and such a quality must be maintained throughout it travelling distance. Based on this issue, barcode inspection is of necessary.

A 2-D barcode is sometime suffering from its printing quality. It fails the barcode reading procedure according to the incomplete information conveyed. In most practical cases, smudge and/or skip printing occurs. Therefore the imperfectness of the barcode can be the crucial cause of reworking. Eye observing inspection is a very time consuming task and it needs operator's experiences. Of long working hours, human can be tired and the productivity declines. Toward this argument, machine inspection is desirable. There are several possible ways to do printed barcode machine inspection. However according to flexibility and cost effectiveness, a cheap webcam and a PC-based software seems to be a good solution.

For machine inspection, image processing tools are unavoidable. Template matching is the process of finding the location of a source image, called a template, inside a test image (input image). The basic template matching algorithm consists the calculation at each position of the image under examination the degree of similarity between the template and the test image. Then, the minimum distortion, or maximum correlation position is taken to locate the template into the examined image. As far as template matching is concerned, Normalized Cross Correlation (NCC) is often the adopted due to its better robustness [1]. The technique of NCC is widely used in object finding, ROI determination, and inspection. The 2 stage matching [2] is practically used when the matching speed is required as the matching speed can be improved significantly.

Histogram and edge detection are also tools that usually used in many kind of inspection. However, for a binarized image histogram can yield a limited power.

In this paper we propose an alternative method for a data matrix 2-D barcode inspection. The barcode size is 0.5x0.5 cm^2 and the data cell is 16x16 cells. The rest of this paper is organized as follows. A data matrix 2D barcode is given in brief in section II. Printed 2-D barcode inspection is elaborated in section III. In this section we detail the use of template matching in barcode area locating as well as barcode finder pattern inspection. The idea of average pixel weight is also given. Such a technique is used for both finder pattern and barcode cells inspection. In section IV we detail the machine inspection of the pre-inspected barcode (eye-observed). Several experiment results are given. In section V, the paper is concluded with the merit of each procedure.

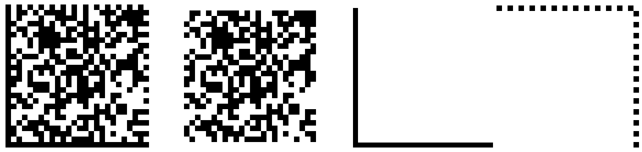
II. MATRIX BARCODE

A. 2-D Barcode

2-D barcode is the development of more 1D barcode containing information designed to by both vertical and horizontal. Allows information contained approximately 4,000 characters or approximately 200 times the 1D barcode. Most products of industries begin with detecting 2D barcodes attached to them, storing data, then comparing these to database and categorizing these products for tracing and/or packaging. Barcodes of this type are, for instance, data matrix, QR code, and PDF417.

B. Data Matrix 2-D Barcode

Data Matrix Barcode was introduced by RVSI Acuity ciMatrix company, USA in 1989. It meets ISO/IEC 16022 and ANSI/AIM BC11-ISS-DATA Matrix standard. The shape of this barcode appears in both rectangle and square. This type of barcode has the maximum storage capacity of 3,116 numeric data or 2,355 characters. These capacities are varied by types of database, for example, 1,556 bytes for binary numbers and 778 for Japanese characters. The Data Matrix comprises two parts:__the data cell is surrounded by a specific pattern called finder pattern. Of its compact size with dense data, the data matrix barcode is often required for a very limited area on an object and a small barcode is needed.



(a) (b) (c) (d)

Figure 1. Data matrix barcode structure example:
(a) Whole barcode, (b) Data cell, (c) and (d) Finder patterns

III. Barcode Printing Quality Inspection

A. *Common Problems*

In most practical cases, the low quality barcode are generated either with smudge or incomplete black portion. The failures are found in the finder pattern area and/or in the barcode cells. The barcode cell pattern generally varies with the information it carries whilst the finder pattern are fixed patterns. Some imperfect barcode images are demonstrated in Fig. 2 below.

a) b) c)

Figure 2. Examples of imperfect printed 2-D barcodes

Our purpose is trying to identify and classify the good and bad barcodes. To identify the imperfectness of the fixed pattern area, the task is fairly simple compared to identifying the imperfectness of the data cells. In the next section we will detail how we can overcome both problems.

B. *NCC Template Matching*

In this section, the procedure of template matching is given in brief. We have two purposes in using this procedure. Firstly we need the location of the barcode. Secondly, upon the matching score we can evaluate how good the barcode. Location of the barcode should be precisely achieved since we need that for barcode decoding as well as for next step pixels weight computation.

Correlation is a technique which can show how strongly pairs of variables are related. Correlation coefficients range from -1.0 to +1.0. The closer range of +1, the more closely one variable is related to the other. The correlation between two signals (cross-correlation) is a standard approach to find out how the two signals are related. It has shown its good applications in pattern recognition and cryptanalysis. Of its kinds, normalized cross correlation (NCC) has also been used extensively in machine vision for industrial inspection including defect detection in complicated images.

Consider Fig. 3. Let *f* be a test image (source image) and *t* be a template image. We want to seek any similarity of the template *t* to any portion of test image *f*. In this particular case, the image size *t* is smaller or equal to *f*. A simple method for measuring similarity or mismatch performed by taking the absolute difference between template image *t* and given test image *f* over a specific region.

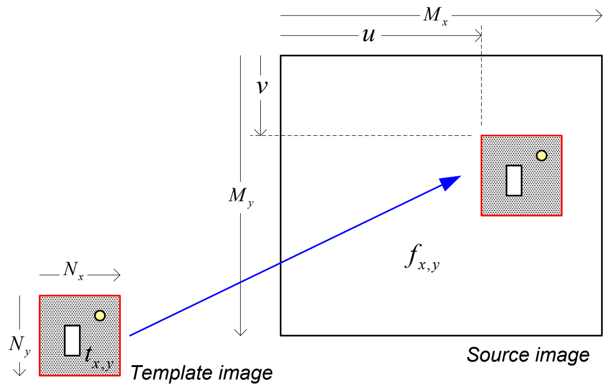


Figure 3. Matching of template *t* into the source image *f*

The maximum value of absolute difference gives the similarity measure. If we take the sum of difference square between template *t* and given image *f* over a region offset by *u* and *v* in each dimension, then we can get

$$d^2_{f,t}(u,v) = \sum_{x,y} \left[f(x,y) - t(x-u,y-v) \right]^2 \quad (1)$$

The above equation (1) can be expanded to,

$$d^2_{f,t}(u,v) = \sum_{x,y} \begin{bmatrix} f^2(x,y) - 2f(x,y)t(x-u,y-v) \\ +t^2(x-u,y-v) \end{bmatrix} \quad (2)$$

The term $\sum_{x,y} \left[t^2(x-u,y-v) \right]$ is fixed for a given template image. Likewise, the term $\sum_{x,y} \left[f^2(x,y) \right]$ is also approximated to be fixed. Then the cross correlation expression given in eq. (3) will give the degree of similarity.

$$c(u,v) = \sum_{x,y} \left[f(x,y)t(x-u,y-v) \right] \quad (3)$$

Direct implementation of eq (3) leads to a problem that image intensity may vary from region to region. The obtained result is not consistent. To avoid such a problem, both means and variances are taken into account. The resulted eq (4) is known as normalized cross correlation (NCC).

$$\gamma(u,v)=\frac{\sum_{x,y}\left[f(x,y)-\bar{f}_{u,v}\right]\left[t(x-u,y-v)-\bar{t}\right]}{\sqrt{\sum_{x,y}\left[f(x,y)-\bar{f}_{u,v}\right]^2\sum_{x,y}\left[t(x-u,y-v)-\bar{t}\right]^2}} \quad (4)$$

where

$\bar{f}_{u,v}$ and $\bar{t}$ are the means of $f(x,y)$ and t respectively.

$$\bar{f}_{u,v}=\frac{1}{N_xN_y}\sum_{x=u}^{u+N_x-1}\sum_{y=v}^{v+N_y-1}f(x,y)$$

and

$$\bar{t}=\frac{1}{N_xN_y}\sum_{x=u}^{u+N_x-1}\sum_{y=v}^{v+N_y-1}t(x,y)$$

In practice to avoid excessive computation, fast and approximated techniques are used to compute eq. (4) [3] [4].

C. Average Pixels Weight

In the grayscale image, the pixel value lies in the range of 0 - 255. For a specific image with the dimension of $N_x \times N_y$, the average pixel weight can be computed by:

$$W_{avg}=\frac{1}{N_xN_y}\sum_{i=1}^{N_x}\sum_{j=1}^{N_y}x_{ij} \quad (5)$$

Where x_{ij} denotes the pixel value.

Equation (5) can also be applied to binarized image where $x_{ij}\in\{0,1\}$. Over any area of interest the average pixel weight can be a kind of information that is usually useful. In this paper we used this information in evaluating the printed quality of data cell area of the barcode.

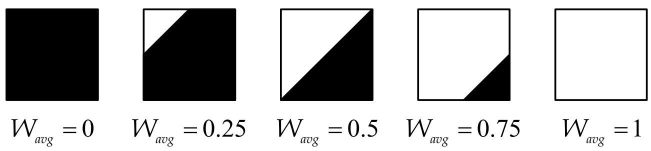


Figure 4. Weight of some example data cells (binarized image)

IV. Experiment and Results

For the ease 2-D barcode inspection, the data matrix barcode is divided into 2 areas; outer finding pattern (see Fig. 1 c, d), and inner data cells (see Fig.1 b). The outer pattern was investigated via matching score whilst the inner pattern was investigated using average pixel weight. The test image was captured at a size of 640x480 pixels. The barcode area is 400x400 pixels. Few tens images are investigated under this study.

D. Template Matching

As shown in Fig 5, four templates for finding pattern are designed. Based on the binarized input image, the sequential matching and ROI fine-tuning procedure is summarized as:

1) First step matching: match template #1 (410x25 pixels) to the test image of 640x480 pixels. When the matching position is found, the head position (x_{01}, y_{01}) is record.
2) Second step matching: Four templates are connected in a chain form (head of template #2 connected to tail of template #1, tail of template #3 connected to tail of template #2, and head of template #4 connected to head of template #1. Definitely head of template #3 connected to tail of template #4). All the template moves together as the head of template #1 moves around the position recorded in the step 1); i.e $(x_{01}\pm10, y_{01}\pm10)$ pixels. At each move the matching score of each template are summed.
3) The maximum score obtained from step 2) notes the best location of the barcode. At this location, the average matching score of those 4 templates is recorded for classification.
4) Forty barcode images (20 pass + 20 rejected) are investigated. The obtained result is shown in Fig. 6.

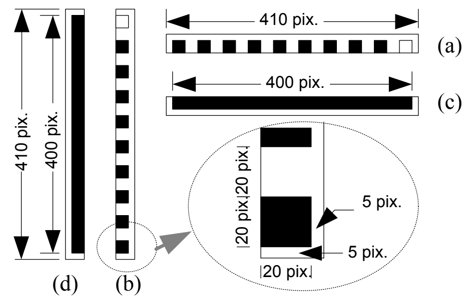


Figure 5. Input Templates (a) Template #1 (b) Template #2 (c) Template #3 (d) Template #4

Form Fig. 6, it is clear that the lower matching score, the high degree of difference. The average score of those pass samples and rejected samples are distinctively grouped. The minimum score of pass sample is 0.90 whilst the maximum score of the rejected sample is 0.88. Those rejected samples have the score of less than 0.9. For good fault acceptant rate (FAR) we can decide the justification point at this value.

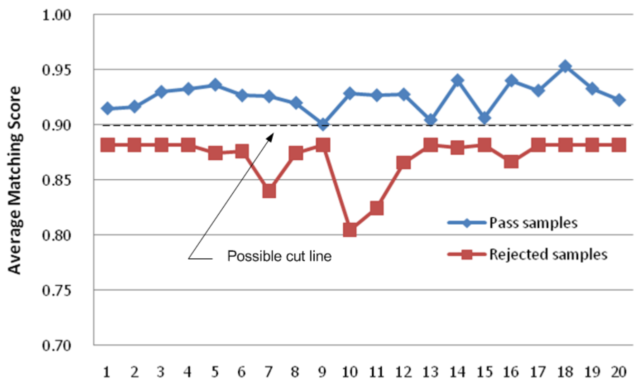


Figure 6. Matching scores of 40 images

E. Average Pixel Weight of the Finder Patterns

Consider the finder patterns shown in Fig.1 and the corresponding template shown in Fig.5; by omitting the white guard edge with 5 pixels width (Fig. 5), we can have the conclusion that: the average pixel weight of template #1 and template #2 is 10/19 = 0.53 and the average pixel weight of template #3 and template #4 is 0. Forty barcode images (20-pass and 20-rejected mixed samples) are investigated.

Shown in Fig. 7 are the average pixel weight of those 4 templates. Quite obvious, the average pixel weight of the pass samples and those of the rejected samples are clearly separable. The rejected samples tend to hold higher average pixel weight compared to the pass samples. These are because of the printing incompleteness. The areas that should be black are not black. They are white-smudge instead. This factor rises up the average pixel weight. The situation is not perfect that template#1 and template#2 should hold the weight of 0.53. The offset value depends on the threshold level imposed during the binarization process. Out-focused images are also sensitive to the obtained weight.

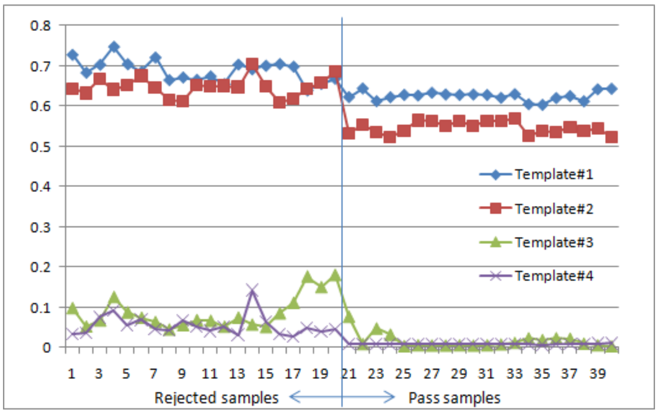


Figure 7. Average pixel weight of rejected samples (1-20) and pass samples (21-40)

Upon the distinctive ranges of the weight as shown in Fig. 7, one can draw the decision line. For instance, weight value of 0.65 and 0.59 should suit well template#1 and template#2 respectively. The given values are based on observation and may be change as the circumstance varies. A sample of which the average weight value above this line is considered to be a low quality one.

F. Average Pixel Weight of the Barcode Cell

The idea of template matching is hard to apply to investigate the quality of barcode cell since the location of the black and white cell tends to vary according to the information. However the average weight of the degraded cell tends to differ from the standard value (0 or 1). The average weight of the not completely white cell can be slightly lower than 1 whilst the average weight of the not completely black cell can be slightly greater than 0. If the cell is precisely located the obtained weight is more reliable and can be used to justify the printing quality.

A template matching detailed previously in sub-section D can tell us the accurate barcode location. Based on the obtained location, the data cells position can be precisely located. As a cell should be purely black or purely white, the average pixel weight should be 0 or 1 respectively. Cells with average pixel weight between 0 and 1 are considered to be imperfect. The assumption seems to work well, but in practice the captured images are not so perfect as said. Blur and/or out-focused images are common ores. Therefore, we have to allow some tolerant for this justification. Barcode cells under investigation are of 16×16 cells (finder patterns are excluded). After binarization, average pixel weight of each cell is taken. Shown in Fig. 8, is the average pixels weight of a good barcode (pass sample). Comparatively, one can observe what is shown in Fig. 8 where the average pixel weight of a fail barcode is plotted. In this plot, most average pixel weight of data cells are less than 0.1 and greater than 0.6. Only few cells hold the weight value between 0.2 and 0.6. Shown in Fig. 9, in contrast, the rejected barcode hold a lot of cell in that range.

We plot the number of cells whose average pixel weight lie the in selected range (i.e. 0.2-0.6). Thirty pass samples and thirty rejected samples are tested. The result is shown in Fig. 10 below. If we draw the decision line, the number of 13 should be the best. According to that decision, fault rejection rate (FRR) should be 3 of 60 or 5%. Similarly, fault acceptant rate (FAR) should also be 3 of 60 or 5%.

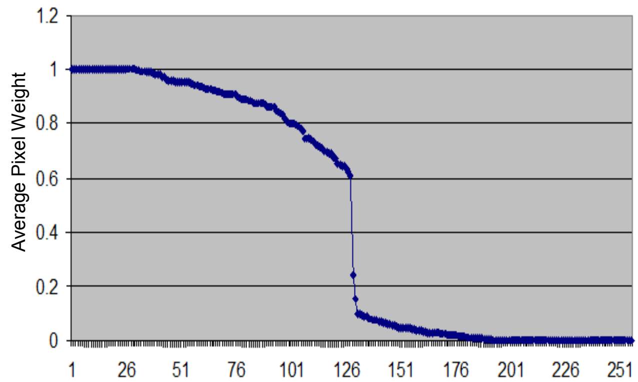


Figure 8. Average pixel weight (data cell) of a pass sample

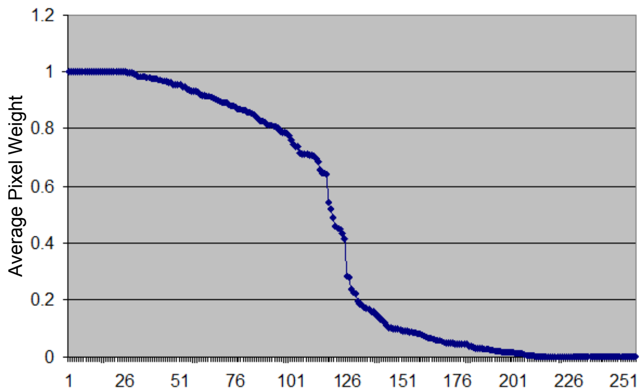


Figure 9. Average pixel weight (data cell) of a rejected sample

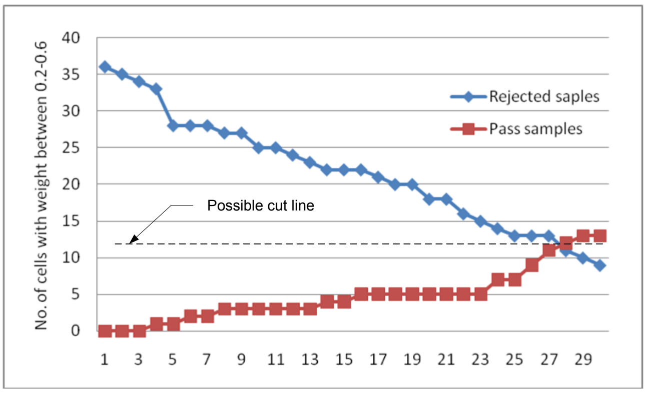


Figure 10. Number of cells with average pixel weight lies between 0.2 and 0.6; (30 pass samples and 30 rejected samples)

One may have an argument that "what is the proper range that we should select"? The answer to that question is; "the decision is made upon the observation of what we get for those pass samples (say Fig. 8 as an example)". Improper range selection can result in both high fault acceptant rate and high fault rejection rate. Consider Fig. 11 where the observation range is made between 0.3 and 0.6. The best decision value should be 0.55. However fairly obvious this range selection is not as good as what we have done previously (i.e. 0.2-0.6). The obtained FAR and FRR are 10% and 11.6% respectively. Therefore the selection of this range resulted in higher FAR and FRR.

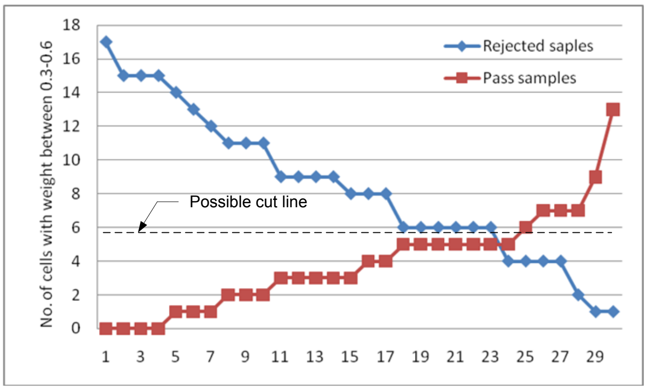


Figure 11. Number of cells with average pixel weight lies between 0.3 and 0.6; (30 pass samples and 30 rejected samples)

V. CONCLUSION

In this paper we have shown two simple-but-effective approaches for inspection of a printed 2-D barcode. Data matrix code is of our interest since that type of barcode is physically small and prone to hold low printing quality. White-smudge generally occurs in both fixed-pattern area such as the finder pattern and variable-pattern area such as data cells. Although normalized cross correlation (NCC) template matching needs more computational resource, it is useful for both barcode area locating and barcode quality inspection. This technique works well for finder pattern detection and inspection. Average pixel weight, in contrast, holds lower computation complexity. It can be used for quality inspection of both finder pattern and barcode cells. Although the proposed method works well whether the image is rotated, the rotated image cannot confirm the barcode orientation. Histogram method should work well for finding barcode orientation. To reduce the computation load of NCC, only template#1 is matched to the full-size source image. The rest templates are matched to the selective image portions resulted from the prior template matching. An average pixel weight technique applied to this work relies on the location of the cells supervised in prior by NCC. The accuracy of the inspection is highly depended on the cell location shifting. Zero-shift in cell position should be maintained to minimize the weight offset. Moreover this technique is also sensitive to threshold level used in the image binarization step since the score is counted based on the portion of black or white color in a cell. On its pros, this method is simple and can be used to inspect the barcode cell area. The good figures of FAR and FAR are basically relying on heuristic observations that could be case by case tuning. In our case, we can obtain FAR of 5% as best. For this technique to be more robust, the heuristic decision method could be replaced by a statistical decision.

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