An Adaptive Recovering Algorithm for The Color Bar Code Image Based on Gamma Transforms

Wanhong Niu¹, Jielin He¹, Xingchao Liu¹, Lingxiao Huang¹, *, Xiaojuan Zhao²

¹School of Information Engineering, Ningxia University, Yinchuan, 750021, China
²School of International Education, North Minzu University, Yinchuan 750021, Ningxia, China

*Corresponding author: huanglx@nxu.edu.cn

Abstract. Aiming at the problem of error reading caused by color deviation under abnormal light source, a color bar code image restoration algorithm adaptively acquiring correction parameters is proposed. According to degree of exposure, the variation range of parameter γ is selected the step size is set. Gamma transformation is then implemented sequentially for the luminance component. Furthermore, the root means square error of enhanced image and source image, as well as the information entropy of enhanced image are sequentially obtained. The best balance point is captured, yielding corresponding γ for image recovery. Finally, the image is segmented based on histogram equalization principle to achieve the best recovery performance. The experimental results show that the algorithm is able to obtain the correction parameters adaptively and recover true color of color bar code images effectively under low-light or non-uniformly intense light of particular light sources.

Keywords: Color bar code, Gamma transformation, Histogram equalization, image restoration.

1. Introduction

Compared with black-and-white barcode images, color barcode images are more sensitive to the influence of light source because of increasing the dimension of color information, which makes it difficult to identify and detect color barcode images. In recent years, the algorithms for color barcode image recognition mainly include: A color barcode segmentation algorithm based on gradient features proposed by Liang Ronghua [1], after extracting the gradient features of the image to obtain the gradient image, divides the gradient image into blocks by discrete cosine transform (DCT), calculates the enhancement coefficient of each block, and then distinguishes the barcode area from the non-barcode area. Finally, the barcode area is segmented according to mathematical morphology and convex hull algorithm, which is too complicated in algorithm design. Li Jieming [2] proposed a color barcode recognition method combining edge detection and nearest neighbor classification. Unfortunately, the experimental process failed to give the detection results of color barcodes under different light sources. A binarization method for color bar code images proposed by Jin Jiashu [3] uses morphological image processing techniques, such as open operation, closed operation, corrosion, expansion, smooth denoising and sharpening, which is easy to cause a small amount of information...
IPEC 2021

Journal of Physics: Conference Series

1952 (2021) 022029
doi:10.1088/1742-6596/1952/2/022029

loss after image processing; Niu Wanhong [4] proposed a color code image restoration method with Otsu method combined with information entropy iterative algorithm to adaptively obtain threshold value, which solved the color shift problem of color code image under abnormal illumination to a certain extent. The disadvantage is that the algorithm is time-consuming when the number of iterations is large; Li Renhe [5] put forward an image enhancement method based on mapping threshold, which uses the principle of gray transformation to determine the dynamic range of image gray to enhance the image, but lacks description of the details of the image; A backlight image detection and correction algorithm proposed by Xu Shaoqiu [6] can effectively remove the halo effect, but the selection of Gamma correction parameters is an experimental comparison method, which is not universal. In view of the shortcomings of the above algorithms, considering that gray-scale transformation can adjust the brightness range of the image nonlinearly, this paper makes further research on the selection of Gamma transformation correction parameters in literature [6], and proposes a color-coded image restoration algorithm that obtains correction parameters adaptively, which completely removes the background information of the image and achieves very ideal restoration results.

2. Gamma transformation principle
Gamma transform is a spatial domain technology that directly operates image pixels [7], and the transformation expression is as follows:

\[ y = (x + \text{eps})^\gamma, \quad x, y \in [0, 1] \] (1)

In formula (1), \( x \) represents the brightness of the input image and \( y \) represents the corresponding brightness of the output image. When transforming, it is necessary to map the gray level range from 0 to 255 to the gray level range from 0 to 1. eps is a function to control the relative accuracy of floating-point numbers, which can avoid the profit-taking phenomenon when \( x \) has 0 value; \( \gamma \) is a key parameter in image grayscale correction, which not only plans the shape of the curve, but also restricts the grayscale mapping form between the input image and the output image, and plays a decisive role in enhancing the low grayscale area or the high grayscale area. When \( \gamma < 1 \), formula (1) is a nonlinear transformation, and the brightness of the low gray area of the image is enhanced; When \( \gamma > 1 \), equation (1) is also a nonlinear transformation, and the brightness of the high gray area of the image is enhanced; When \( \gamma = 1 \), equation (1) is a linear transformation, and the gray area of the image is unchanged. An example of the three mapping modes is shown in Figure 1.

![Figure 1. \( \gamma \) mapping](image-url)
The `imadjust` function is a basic tool to transform gray image, and its formula is:

\[
G = \text{imadjust}(F, [\text{low}-\text{in} \ \text{high}-\text{in}], [\text{low}-\text{out} \ \text{high}-\text{out}], \gamma)
\]  

(2)

In formula (2), when \(\gamma < 1\), the gray value at the low-in end in \(F\) is lower, which corresponds to the increase of gray value in \(G\), that is, the gray change range is stretched, while the gray value at the high-in end in \(F\) corresponds to \(G\), which compresses the gray value range and brightens the whole image. When \(\gamma > 1\), the gray value at the low-in end in \(F\) corresponds to \(G\), which is reduced, that is, the gray value range is compressed, while the gray value near the high-in end in \(F\) corresponds to \(G\), which stretches the gray range and darkens the whole image [8]. Because the Gamma transformation in these two cases is a nonlinear transformation, it can not only change the contrast of the image, but also enhance the detail information, thus improving the visual effect of the whole image.

3. Algorithm design and evaluation

3.1. Algorithm design

Gamma transformation changes the contrast of the image, which leads to the root mean square error (RMSE) before and after image transformation, and also leads to the change of image information entropy (\(H\)) after transformation [9]. From the point of view of the selection of correction parameter \(\gamma\) in the Gamma transformation process, there is a close relationship between the root mean square error and the image information entropy, that is, the best \(\gamma\) parameter should not only make the RMSE value change greatly, but also make the \(H\) value reach the maximum, so as to obtain the ideal enhancement effect. Therefore, the algorithm design idea in this paper is to transform the color code image into Ycbcr color space, keep the color component unchanged, and only enhance the brightness component, so as to ensure the consistency of the three channels of RGB color space information. Secondly, through Gamma transformation, the gray scale range of color code images is changed as a whole, and the contrast is increased. The key step in this process is how to select \(\gamma\) parameters accurately. In this paper, according to the exposure characteristics of the image, the change range of \(\gamma\) parameters are properly planned, and the RMS difference before and after image transformation and the information entropy of the transformed image are calculated in turn by using a smaller \(\gamma\) transformation step. By normalizing these two groups of data, the best balance point is captured, and the corresponding \(\gamma\) value is obtained as the freeze-frame parameter of Gamma transformation to restore the image. In this way, the algorithm has the ability to obtain parameters adaptively. According to Figure 2, the experimental analysis of the algorithm is as follows.
The $\gamma$ step size set in the algorithm is 0.001, and the transformation range is between 0.01 and 0.05. It can be seen from the curve in fig. 2 that when the parameter $\gamma=0.025$, the root mean square error and information entropy meet or approach values, and the value of root mean square error is larger at this time, which indicates that the brightness of the two gray-scale images before and after transformation has been greatly enhanced; However, if the value of information entropy is large, it means that the image is still rich in information after enhancement, and this intersection or close value is exactly the desired result of the algorithm designed in this paper. Experiments show that $\gamma=0.025$ or the value to the right of $\gamma$ (+0.005) is the best transformation parameter.

Finally, the histogram equalization principle is used to further remove the background information and strengthen the barcode area, so as to segment the barcode from the background of different light sources.

The flow chart of color code image restoration algorithm is shown in Figure 3.
3.2. Algorithm evaluation

Two performance evaluation methods, root mean square error (RMSE) and structural similarity (SSIM), are used to evaluate the restoration effect of color-coded images.

Mean square error (MSE) reflects the difference between variables. For images $X$ and $Y$, the mean square error between them can be defined as:

$$MSE = \frac{1}{M \times N} \sum_{i=1}^{M} \sum_{j=1}^{N} (X(i, j) - Y(i, j))^2$$  \hspace{1cm} (3)

$$RMSE = \sqrt{MSE}$$  \hspace{1cm} (4)

Equation (3) is a mean square error formula, where $X(i, j)$ is a color component of the original image, $Y(i, j)$ is the corresponding color component of the restored image, and $M$ and $N$ are the number of rows and columns of the color component respectively, that is, the resolution of each color component is $M \times N$. Formula (4) is the root mean square error formula, which is the arithmetic square root of the mean square error. The smaller the RMSE value, the better the quality of the restored image.

Structural Similarity (SSIM) model is defined as [10]:

$$SSID = [l(X, Y)]^{\alpha}[c(X, Y)]^{\beta}[s(X, Y)]^{\gamma}$$  \hspace{1cm} (5)

In formula (5),

$$l(X, Y) = \frac{2\mu_X\mu_Y + c_1}{\mu_X^2 + \mu_Y^2 + c_1},$$

$$c(X, Y) = \frac{2\sigma_X\sigma_Y + c_2}{\sigma_X^2 + \sigma_Y^2 + c_2},$$

$$s(X, Y) = \frac{\sigma_{XY} + c_3}{\sigma_X\sigma_Y + c_3},$$

They are the brightness correlation function, contrast correlation function and structural similarity correlation function of two images, where $\mu_X$ and $\mu_Y$ are the average values of images $X$ and $Y$; $\sigma_X$, $\sigma_Y$ is the variance of image $X$ and $Y$; $\sigma_{XY}$ is the covariance of image $X$ and $Y$; $c_1 = (k_1L)^2$, $c_2 = (k_2L)^2$, $c_3 = (c_2 / 2)^2$ are all small constants, in order to avoid zero denominator, $k_1 << 1$, $k_2 << 1$; Parameters $\alpha > 0$, $\beta > 0$ and $\gamma > 0$ are the weight coefficients of the three; $L$ is the value range of image pixel values, and $L = 255$ for 8-bit grayscale images. The larger the SSIM value, the closer the brightness, contrast and structure of the restored image is to the original image, and the better the image quality.

4. Experimental result

The algorithm is implemented by Matlab2014 b compiler on the computer of Intel(R) Core (TM)i5 and Win 7sp1×64 system. The material in Figure 4(a) comes from the self-coded color Chinese code image, while the abnormal illumination color Chinese code image is collected from two different light source scenes: one is the indoor or outdoor low illumination scene, which is characterized by underexposure, dim background and overall color biased towards the color of the light source, as shown in Figure 4(b); The other is the scene under indoor or outdoor strong light, which is characterized by overexposure, partial light color and information loss in details, as shown in Figure 4(c). For the convenience of experimental comparison, the resolutions of these two images are corrected to be the same as the coded image, that is, 129*129 ppi.
For fig. 4(b), the algorithm in this paper and three other similar algorithms restore the image, and the visual effect is shown in fig. 5.

From the sub-images (a), (b), (c) and (d) in Figure 5, it can be seen that the restoration effect of the four algorithms on the given low-illumination color code image is very ideal, and all of them can eliminate dim background information. However, the neighboring color blocks in the four corners of the sub-image (a) or (b) have convex hull or slight false edges, which is related to the morphological image processing technology adopted in literature [1] and [3], that is, the operations such as expansion and corrosion are easy to cause the increase or loss of trace information, but have little influence on the correct recognition of bar codes. However, sub-image (C) and sub-image (D) have the best effect, and their visual effects are very similar to those of the source coded image. It is difficult to find the subtle differences between them without special equipment.

(2) Restoration of color code image under strong illumination

For overexposed color code images such as Figure 4(c), there is no need for gray scale stretching. In this paper, the algorithm chooses the Gamma transformation with parameter $\gamma = 1$, that is, it does not change the mapping range of the image gray area. The visual effects of the restored images by the four algorithms are shown in Figure 6.
From the observation of each sub-image in Figure 6, it can be found that the restoration effect of the proposed algorithm and the other three algorithms for a given color code image with uneven strong illumination is still very good, and they all have good color restoration ability. Although the observation effect of sub-images (a) and (b) is slightly lost in detail, the barcode itself has certain error correction ability during decoding, which can still meet the requirements of color barcode detection and recognition. Sub-image (c) uses the threshold segmentation method and the text method of sub-image (d), which show that the edge contour is neat and the clearest degree is the highest. Generally speaking, the size of barcode image is small, so it is difficult to find the difference of performance of each algorithm only from the visual effect. In order to objectively verify the performance difference between the proposed algorithm and the other three algorithms, Table 1 gives the objective evaluation results of the restoration effect of these two-color code images, namely RMSE and SSIM.

Table 1. Performance evaluation of four algorithms

| Algorithm         | Low illumination color code | Strong illumination color code |
|-------------------|-----------------------------|--------------------------------|
|                   | RMSE           | SSIM   | RMSE | SSIM       |
| Literature [1]    | 4.609 7        | 0.997 5 | 1.204 8 | 0.999 7    |
| Literature [3]    | 10.775 5       | 0.985 4 | 10.307 6 | 0.990 6    |
| Literature [4]    | 1.232 0        | 0.999 6 | 0       | 1          |
| The algorithm in this paper | 4.526 6  | 0.997 7 | 0       | 1          |

It can be seen from formulas (4) and (5) that the smaller the value of the root mean square error, the better the restored image quality, while the larger the value of similarity, the better the restored image quality, but there is no clear definition value. The data in Table 1 show that the performance of the algorithm in this paper and the algorithm in reference [4] is the best, that is, the mean square error value is 0, the similarity value is 1, and the image can be restored 100%. For the restoration of low illumination color code images, the performance of the algorithm in reference [4] is the best, that is, the mean square error value is the smallest (1.232 0) and the similarity value is the largest (0.999 6); The algorithm in this paper and the algorithm in reference [1] are slightly inferior, but the similarity value can be as high as above 0.997 5, which fully meets the requirements of color code image detection and recognition, and is still a good color code image restoration algorithm.

In addition, considering the real-time performance of the algorithm, Table 2 shows the comparison of the execution time between the proposed algorithm and the other three algorithms.
When color code image is restored by the algorithm in reference [1], the method is to obtain gradient image first, then divide the gradient image into blocks by DCT transform, and calculate the enhancement coefficient of each block, and the execution time is about 0.15s; The algorithm in reference [3] and the algorithm in reference [4] are based on the iterative method to get the threshold, and the execution time depends on the iteration step and iteration times, which is usually more than 0.25s, so the algorithm is time consuming. It can be seen from Table 2 that the algorithm in this paper has the shortest execution time within 0.1s. Under normal circumstances, the resolution of color code barcode images is generally low, and it is acceptable that the execution time of color restoration algorithm plus barcode decoding should not exceed 0.5s. The execution time given by the above four algorithms shows that each algorithm has good real-time processing ability.

5. Summary
Because color barcode increases the dimension of color information, it is much more difficult to detect images obtained under abnormal light source than traditional two-dimensional code image detection. Therefore, this paper presents a restoration algorithm based on Gamma transformation principle and histogram equalization principle, which can effectively restore the color bar code image under the influence of specific light source, and the transformation parameters of the algorithm can be obtained adaptively, thus overcoming the defect that the same kind of algorithm has too many parameters and is not universal. Experimental data show that the similarity between the restored image and the real image is above 0.9975, even 1, whether it is for low illumination color barcode image or high illumination color barcode image. The execution time of the algorithm is also less than 0.1s, which has the ability of real-time barcode processing. This algorithm provides an effective method for color barcode image restoration under abnormal light source.

Acknowledgments
This work was financially supported by the scientific research project of colleges and universities in Ningxia (NGY2020009), the major R & D project of Ningxia Science and Technology Department (2020BEB04018), the Fundamental Research Funds for the Central Universities, North Minzu University (2021XYSGJ01) and the Scientific Research Innovation Project of First-Class University in Western China (ZKZD2017005).

References
[1] Ronghua L, Zhi L, Chong C. Research on segmentation algorithm of 2D color bar code based on mobile phone [J]. Journal of Zhejiang University of Technology, 2011, 39(05): 566-570.
[2] Jieminig L, Jianing S, Fubin W. A Generation and Recognition Algorithm for Two dimensional Color Bar code [J]. Journal of Fujian Computer, 2017, 33(05): 1-2+18.
[3] Jiapeng J. A Banalization method for color two-dimensional code images [J]. Science and technology and enterprise, 2016(04): 83-84.
[4] Wanhong N, Xuande Z. An application in image restoration of color bar-code based on Otsu method and iterative algorithm of information entropy [J] Journal of Qingdao University of Science and Technology (Natural Science Edition), 2016, 37(01):113-118.
[5] Ronghe L. A Novel Method of Image Enhancement Based on Mapping Threshold [J] Microelectronics & Computer, 2010, 27(11): 1-3+9.
[6] Shaoqiu X, Qun Y, Xiaoyun Z, et al. Detection and correction of backlight images [J]. Computer Engineering and Applications, 2017, 53(21): 174-178.

[7] BEDI S S, KHANDELWAL R. Various image enhancement techniques [J]. International Journal of Advanced Research in Computer and Communication Engineering, 2013, 2(3):1605-1609.

[8] GONZALEZ R C, Woods R E. Digital image processing [M]. 3rd Edition. [S. l.]: Prentice Hall, 2008.

[9] Fei G, Cong W, Donghang J. An Image Registration Algorithm Based on Block Information Entropy and Characteristic Scale [J] Transactions of Beijing Institute of Technology, 2016, 36(11):1194-1199.

[10] Yong Z, Weiqi J. Image Fusion Assessment Method Based on Structural Similarity and Region of Interest [J]. Acta Photonica Sinica, 2011, 40(02): 311-315.