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Illumination Compensation Algorithm for Unevenly Lighted Document Segmentation

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Abstract

For the problem of segmenting the unevenly lighted document image, this paper proposes an illumination compensation segmentation algorithm which can effectively segment the unevenly lighted document. The illumination compensation method is proposed to equivalently convert unevenly lighted document image to evenly lighted document image, then segment the evenly lighted document directly. Experimental results show that the proposed method can get the accurate evenly lighted document images so that we can segment the document accurately and it is more efficient to process unevenly lighted document images than traditional binarization methods. The algorithm effectively overcomes the difficulty in handling uneven lighting and enhances segmentation quality considerably.

Keywords*: unevenly lighted, document image, image segmentation, illumination compensation*

1. Introduction

The purpose of document image segmentation is to separate characters and figures from the background, and produce a clear and distinct display of the document text, which serves as the pre-process for subsequent process, including skew detection, layout analysis and character recognition. The performance of these processes is crucially dependant on the quality of the segmentation.

Most of the existing segmentation algorithms [1-6] are designed for the evenly lighted images. However, as the rapid popularization of the portable devices with photo-taking function, such as digital camera and mobile phone, it is convenient to acquire document images in natural illumination environment. Thus, effective segmentation for these unevenly lighted images will enormously extend the capability in document image processing and reduce the cost in document analysis and recognition.

During the recent decades, there have been various researches on unevenly lighted document image segmentation. The proposed binarization methods include fixed window method [7], in which threshold for each pixel is computed based on the information of a fixed sized neighborhood, and the method of adaptive window selection [8], in which neighborhood size is determined upon the evaluation of the amount of foreground text. However, these methods have one common defect that large background regions may be incorrectly segmented as the text regions, resulting in “ghost objects”.

In reference [9], Stockhan proposed a visual model, which the gray level of a pixel is the product of the illumination and the reflectance. The model is analyzed in reference[10], with the conclusion that tracking the variations in illumination is an essential element for achieving high quality segmentation from unevenly lighted images. Hence, a useful way is to convert first unevenly lighted document image into an evenly lighted document image. Tan[11] reported such a method that estimates and compensates shading degradation and achieved good segmentation results. Therefore, it is natural to forward research in this direction for more appropriate and accurate compensation method.

In this paper we take the advantage of Stockhan’s visual model and estimate illumination distribution by interpolation in fixed window. Our method has two merits: 1) the visual model is physically realistic; 2) estimation can be iteratively implemented for higher accuracy.

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The paper is arranged as follows. Section 2 is a detailed introduction of the illumination compensation method. Section 3 shows some experimental comparisons between the new method and the existing ones. A conclusion is given in Section 4.

2. Illumination compensation method

2.1. Stockhan's visual model

In Stockhan's visual model, a gray level image $h(x,y)$ is modeled as the product of an illumination $i(x,y)$ and a reflectance $r(x,y)$:

$$h(x,y)=i(x,y)\cdot r(x,y). \tag{1}$$

For the document image, $r(x,y)$ is a binary function, in which 0 represents foreground text and 1 represents background paper. Thus, under an even illumination i_0, the gray level image of a document is

$$h^0(x,y)=\frac{i_0}{i(x,y)}\cdot h(x,y). \tag{2}$$

2.2. Estimation of illumination distribution

Given a document image with width l_w and height l_h (in unit of pixel), we divide it into windows of size $l_s \times l_s$. Thus, the image contains $s_w \times s_h$ windows in total, where $s_w=[l_w/l_s]$ and $s_h=[l_h/l_s]$, and $[a/b]$ denotes the integral quotient.

Let $h(m,n)$ denotes the gray value of the pixel in m-th row and n-th column in the original image, and $Q(i,j)$ denotes the illumination at the center of the window in i-th row and j-th column. $Q(i,j)$ is computed approximately by taking average illumination in the window,

$$Q(i,j)=N_s^{-1}\sum_{m=l_s\cdot i}^{l_s(i+1)-1}\sum_{n=l_s\cdot j}^{l_s(j+1)-1} h(m,n), \tag{3}$$

Where, $N_s=l_s^2$.

2.3. Interpolation for Illumination Compensation

Illumination distribution in window is calculated by the interpolation in $Q(i,j)$, $Q(i-1,j)$, $Q(i+1,j)$, $Q(i,j-1)$ and $Q(i,j+1)$. The interpolation is performed by a bilinear function,

$$F^0(y,x)=a_{0,0}^0(i,j)+a_{0,1}^0(i,j)x+a_{0,2}^0(i,j)x^2+a_{1,1}^0(i,j)xy+a_{1,0}^0(i,j)y+a_{2,0}^0(i,j)y^2. \tag{4}$$

The coefficients in formula (4) are

$$a_{0,0}^0(i,j)=f(i,j),\quad a_{1,1}^0(i,j)=0,$$

$$a_{0,1}^0(i,j)=\frac{1}{2l_s}\left[Q(i,j+1)-Q(i,j-1)\right],$$

$$a_{1,0}^0(i,j)=\frac{1}{2l_s}\left[Q(i+1,j)-Q(i-1,j)\right],$$

$$a_{0,2}^0(i,j)=\left\{\frac{1}{2}\left[Q(i,j+1)+Q(i,j-1)\right]-a_{0,0}(i,j)\right\}/N_s,$$

$$a_{2,0}^0=\left\{\frac{1}{2}\left[Q(i+1,j)+Q(i-1,j)\right]-a_{0,0}(i,j)\right\}/N_s,$$

Where, $N_s=l_s^2$.Thus the gray value of pixel (m,n) in window (i,j) is

$$h^0(m,n) = \frac{i_0}{F(i,j)} \cdot h(m,n), \tag{5}$$

Where, $F^0(i,j) = a^0_{0,0}(i,j) + a^0_{0,1}(i,j)m + a^0_{0,2}(i,j)m^2 + a^0_{1,1}(i,j)mn + a^0_{1,0}(i,j)n + a^0_{2,0}(i,j)n^2$.

For windows (i,j) lying at the left and right margin, we set $Q(0,j)=Q(2,j)$ and $Q(s_w+1,j)=Q(s_w-1,j)$. For windows lying at the top and bottom margin, we set $Q(i,0)=Q(i,2)$ and $Q(i,s_h+1)=Q(i,s_h-1)$.

2.4. Obtaining Evenly Lighted Image

In formula (5), i_0 is a constant to be determined. We set $i_0 = Q^0_{\max} = \max\{Q^0(i,j)\}$ to make all the values of $h^0(m,n)$ lying in gray level of 0~255. Then, an evenly lighted image is obtained by applying following calculation:

$$h^0(m,n) = \frac{Q^0_{\max}}{F^0(i,j)} \cdot h(m,n). \tag{6}$$

2.5. Global Segmentation Algorithm

As $h^0(m,n)$ is an evenly lighted image, any global segmentation algorithm is suitable for the binarization. We have tested some typical global segmentation algorithms, and found there is little difference in their performance, so we prefer to use Otsu's algorithm[2] because of its simplicity and quality. We briefly describe Otsu's algorithm. If an image is segmented by a threshold T, the probability of the occurrence of foreground pixels is ω_0 and their average gray value is μ_0, while these for background pixels are ω_1 and μ_1. The average gray value of the entire image is

$$\mu = \omega_0 \cdot \mu_0 + \omega_1 \cdot \mu_1.$$

The best segmentation threshold T is the gray value that makes the variance σ, defined in the following formula, achieving its maximum:

$$\sigma = \omega_0 \cdot (\mu_0 - \mu)^2 + \omega_1 \cdot (\mu_1 - \mu)^2. \tag{7}$$

In fact, variance σ is the measure of gray value distribution and contrast between foreground and background. This value will diminish if background is incorrectly segmented as foreground and vice versa, so the maximum of variance means the minimum probability of incorrect segmentation. Apply Otsu's algorithm on the image $h^0(m,n)$ gives a binary image, $D^0(i,j)$.

2.6. Iterative Calculations

Illumination estimation in section 2.3 gives the correct gray distribution of the document image under an evenly lighting, only if the populations of foreground equal to those of background pixels in all the windows. This requirement is hardly satisfied in reality, but this difficulty can be circumvented by an iterative calculation for the compensated illumination. As $D^0(i,j)$ gives, to some extent, the distribution of foreground and background, the illumination estimation is improved by taking count of $D^0(i,j)$, and the average gray in window (i,j) is

$$Q^1(i,j) = \frac{1}{N^1(i,j)} \sum_{i,j \in \{D^0(i,j)=255\}} h(m,n), \tag{8}$$

Where, $N^1(i,j)$ is the number of background pixels in window (i,j). Similarly, the interpolation function described in section 2.3, with coefficients, $a_{0,0}^1(i,j)$, $a_{0,1}^1(i,j)$, $a_{0,2}^1(i,j)$, $a_{1,1}^1(i,j)$, $a_{1,0}^1(i,j)$, $a_{2,0}^1(i,j)$, is calculated to obtain a new illumination function $F^1(i,j)$. Setting $Q_{\max}^1 = \max\{Q^1(i,j)\}$, and the corresponding calculating result in an evenly lighted image with a improved illumination compensation,

$$h^1(m,n) = \frac{Q_{\max}^1}{F^1(i,j)} \cdot h(m,n). \tag{9}$$

Applying Otsu's algorithm gives a new binary image $D^1(i,j)$. In general, the iterative calculations will approach to the real illumination distribution, and experiments show also that the improvements increase as the iterations are performed repeatedly. But, in practice, taking only the first few iterations is sufficient to produce a good evenly lighted image.

2.7. Improved Locally Adaptive Binarization

Global segmentation algorithm usually cannot guarantee the quality for every character in the document image, while locally adaptive method will lead to "ghost objects". Based on the evenly lighted image, an adaptive binarization is formulated, which take the advantages of locality of the window method and can avoid "ghost objects". If an evenly lighted image $h^i(m,n)$ is produced, we perform following operations:

Divide $h^i(m,n)$ into blocks of size $l_t \times l_t$ to obtain $s_{w'} \times s_{h'}$ sub-windows, where $s_{w'} = [l_w / l_t]$ and $s_{h'} = [l_h / l_t]$. l_t may not equal to l_s, and usually $l_t \ge l_s$. Compute k_g^* as Otsu's threshold for $h^i(m,n)$.

Treat every sub-window as a pixel and mark its location as (i',j'). Compute variance σ_B (see section 2.5) for every sub-window, and take it as the pixel's gray value. Hence we built a quasi-image $\sigma_B(i',j')$.

Compute k^* as Otsu's threshold for quasi-image $\sigma_B(i',j')$.

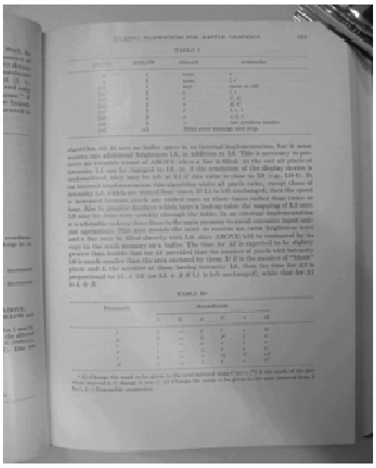
Binarize every sub-window in $h^i(m,n)$ according to k^*:

If $\sigma_B(i',j') > k^*$, which indicates high information quantity (foreground text region), binarize it by using sub-window's local threshold.

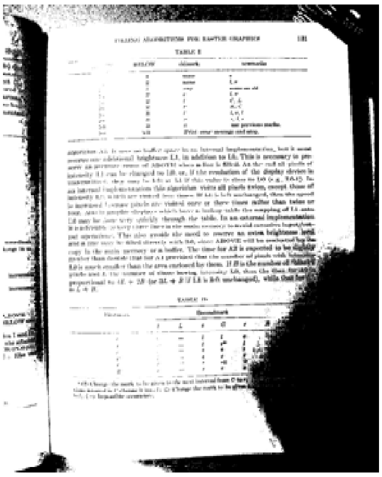
If $\sigma_B(i',j') \le k^*$, which indicates low information quantity (background region), binarize it by using global threshold k_g^*.

3. Results and Discussions

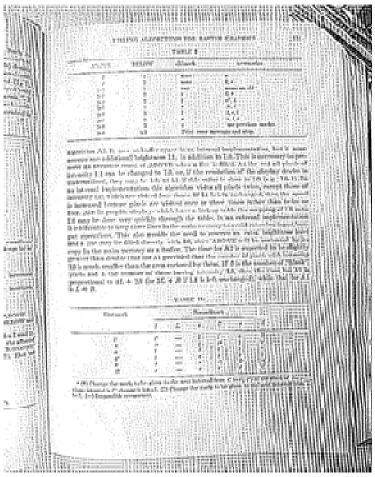
Figure 1(a) is an image of uneven illumination. We apply some segmentation algorithms, including Otsu's algorithm in Figure 1(b), Niblack's algorithm [12] in Figure 1(c) with $k = -0.2$ and Sauvola's algorithm [7], [11] in Figure 1(d) with $k = 0.5$ and $R = 128$. Obviously these results are not satisfactory. Figure 1(e) is an compensated image, $h^0(m,n)$, with window size 15×15. The result shows that brightness of the whole page is converging while contrast between text and paper is increased. Figure 1(f), 1(g) and 1(h) give the binary images, which are produced respectively by applying Otsu, Niblack and Sauvola's algorithms on the image $h^0(m,n)$, and they are apparently better than previous ones.



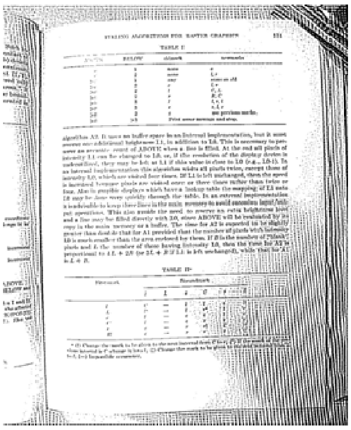
(a).Test image



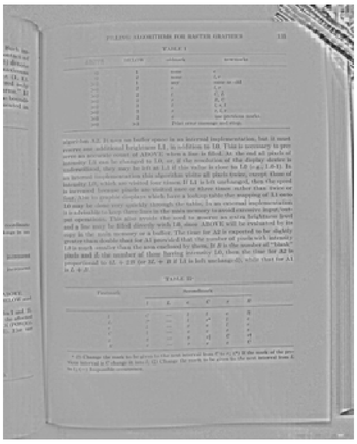
(b). By Otsu's algorithm



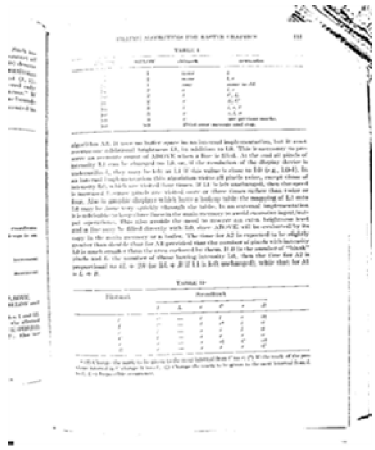
(c). By Niblack's algorithm



(d). By Sauvola's algorithm

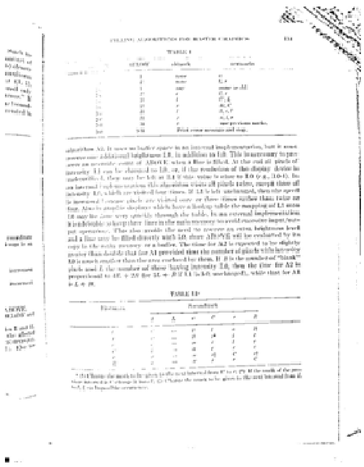


(e). First-time compensation



(f). By applying Otsu's algorithm upon(e)

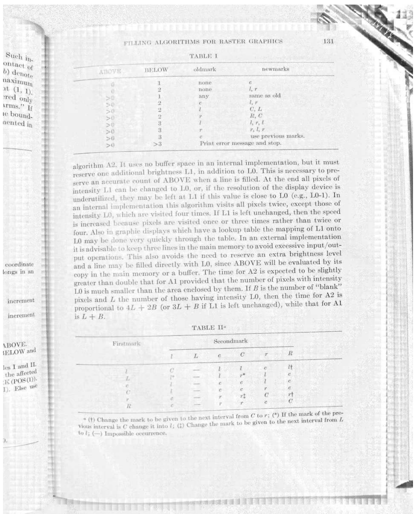
(g). By applying Niblack's algorithm upon(e)



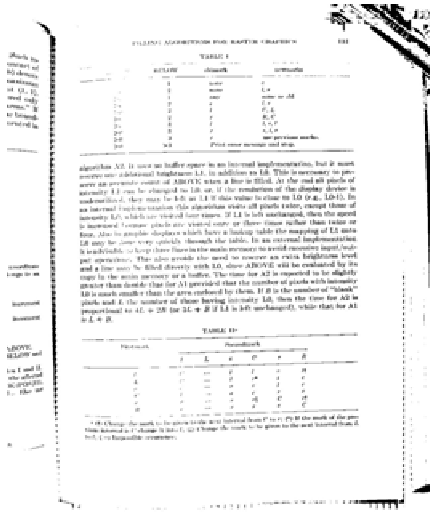
(h). By applying Sauvola's algorithm upon(e)

Figure1. Illumination compensation segmentation for unevenly lighted document image

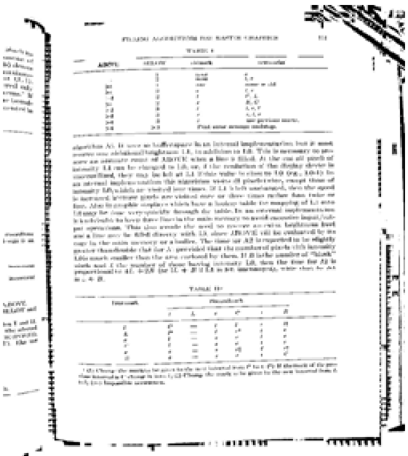
The image $h^2(m,n)$ (in Figure 2(a)) is the result of applying the iterative calculation thrice, which shows much more smoothed illumination and have an evident contrast between the foreground and the background. Figure 2(b) shows the result of applying Otsu's algorithm upon $h^2(m,n)$, and it is much better than Figure 1(b) and 1(f). To further improve segmentation quality, sub-window of size 15×15 is used to segment $h^2(m,n)$, and the result is given in Figure 2(c). From comparison in Figure 2(d), it is clear that characters are better binarized in Figure 2(c) than those in Figure 2(b).



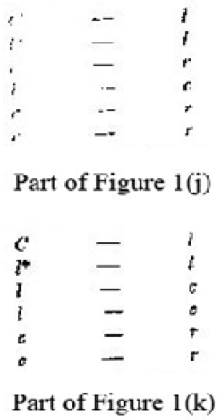
2(a). Third-time compensation



2(b). By applying Otsu's algorithm upon(e)



2(c). Improved segmentation upon(i)



2(d). Comparison between (j) and (k)

Figure 2. Illumination compensation segmentation Result

Experiments illustrates, in some extent, that the new method has circumvented the difficulty in handling uneven illumination and improve segmentation quality.

4. Conclusion

This paper applies Stockhan's visual model to document image segmentation and proposes a new illumination compensation method to obtain evenly lighted image from unevenly lighted image. Then the image is binarized by using an improved locally adaptive method to avoid "ghost objects" and preserve character strokes. Unevenly lighted images produced in the complex illumination environment can also be treated by this method.

In the first International Document Image Binarization Contest organized in the context of ICDAR 2009 conference (DIBCO 2009), the general objective of the contest is to identify current advances in document image binarization using established evaluation performance measures. The illumination compensation method for unevenly lighted document segmentation gets the sixth place in the 43 submitted method [13]. As the testing images in DIBCO 2009 are uniformity lighted, the illumination compensation Method can achieve better performance for the Unevenly Lighted images.

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