Shading Extraction and Correction for Scanned Book Images

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***Abstract*—When one scans document pages from a bound book, shading artifacts are commonly occurred in the book spine area. In this letter, we propose a general-purpose method for image shading correction based on an assumption that the reflectance function of the page surface is piecewise constant and the illumination function is smooth. The proposed method is able to completely correct more general types of shading artifacts which are nonuniformly distributed along the book spine. Comparison experiments on a synthetic and a variety of real scanned book images demonstrate the feasibility and effectiveness of the proposed method.**

***Index Terms*—Document image processing, image restoration, optical model, shading correction.**

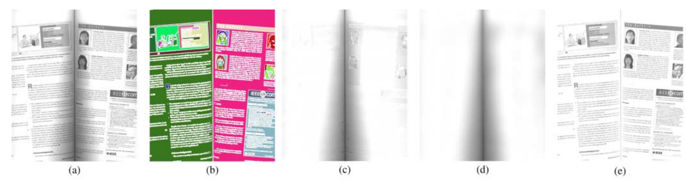

Fig. 1. Shading correction for scanned book image. (a) Image with nonuniformly distributed shading artifacts. (b) Image regions with uniform reflectance values. (c) Extracted shading image. (d) Smoothing shading image with RBF. (e) Shadow-free image.

I. Introduction

NOWDAYS, a scanner is becoming a common device in the modern office for converting a paper document into its digital format to facilitate archiving, transmission, online accessing and retrieving, etc. However, the convenience of using a scanner is also accompanied with some image quality problems. For example, when one scans a document page from a bound book, it is often observed that the resulting image suffers from shading artifacts and geometric distortion in the spine area of the book. This is generally because the curled page surface near the book spine region cannot be fully flattened onto the glass platen of the scanner. Such image quality deterioration will not only impair the readability of the scanned documents, but it will also cause some significant problems in the subsequent process of document image analysis.

Traditional methods for document shading correction use local or adaptive binarization techniques to remove image shading [1]–[3]. These methods can produce satisfactory outputs which are sufficient for OCR. However, they are limited since some useful information in the gray-level photographic regions may be lost after image binarization.

Since it was noticed that image shading and distortion occur correlatively, some efforts have been made to correct shading and distortion simultaneously by using document's 3-D geometry [4]–[7]. To obtain the surface shape, many techniques have been proposed, in which shape from shading (SFS) techniques are much preferred for it does not require any special setup. However, how to robustly estimate the 3-D geometry of the page surface is difficult and computationally expensive. Cylindrical page surface is thus often assumed practically to simplify the problem [6], [7]. This assumption holds for images with uniformly distributed shading, but it is limited if the shading in the book image appears differently between the top edge and bottom edges [see Fig. 1(a)].

Some other methods are also proposed for shading correction which work directly from the images. Tsoi *et al.* proposed a method [8] which models the curled page as a ruled surface. Based on this model, they formulated shading extraction as a problem of scale change estimation between two image columns. Brown *et al.* proposed a boundary interpolation-based method [9] for shading correction. This method can produce good results for a variety of image shading but is restricted to iso-parametric folding lines. Zhang *et al.* proposed a more general method [10] for document shading extraction and correction by using an image inpainting technique. The method works efficiently for shading correction but is limited to document images with narrow objects.

In this letter, based on an assumption that the reflectance function of the page surface is piecewise constant and the illumination function is smooth, we propose a general-purpose method for shading extraction and correction in scanned book images. Our method does not depend on the commonly used cylindrical assumption on the page surface. It is able to completely correct more general types of image shading which is nonuniformly distributed along the book spine. Moreover, our method has extended Zhang's method and can be applied to a variety of real scanned book images with a large area of pictures.

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II. Shading Extraction and Correction

A. Proposed Method

According to the optical imaging model [11], the intensity of a scanned image $I(x,y)$ can be expressed as follows:

$$I(x,y) = L_0 \cdot R(x,y) \cdot C(x,y) \tag{1}$$

where L_0 is the source intensity of the scanner light, and $R(x,y)$ and $0 < C(x,y) \leq 1$ are the reflectance value and the illumination reduction at point (x,y), respectively. Once $C(x,y)$ is calculated, we can recover the image free from shadow as

$$\hat{I}(x,y) = k \cdot e^{\log I(x,y) - \log C(x,y)} \tag{2}$$

where $\hat{I}(x,y)$ is the shading-corrected image and k is a prescribed constant. An appropriately selected k can attenuate the background noises in the shading area, which are caused due to the transmission of printed contents on the back of the scanned page.

However, due to the unknown reflectance component $R(x,y)$, solving $C(x,y)$ from (1) is ill-posed. To address this problem, we assume that $R(x,y)$ is piecewise constant and $C(x,y)$ is smooth. Since the page surface is generally smooth, and the printed contents are of high contrast to the background, this assumption is appropriate for most scanned book images.

Converting (1) into its logarithm form, we have

$$i(x,y) = l_0 + r(x,y) + c(x,y). \tag{3}$$

The corresponding function in the logarithm domain is denoted by its lowercase character. Let Ω_r be a piece of region within which $r(x,y)$ is constant and $\Omega^1 = \bigcup_r \Omega_r$. Further calculation of the gradient functions at each side of (3) in Ω^1 gives

$$\nabla i(x,y) = \nabla r(x,y) + \nabla c(x,y) = \nabla c(x,y), \quad (x,y) \in \Omega^1. \tag{4}$$

In fact, (4) provides the necessary constraints for calculating $c(x,y)$.

To solve a smooth $c(x,y)$ from (3), we first introduce the following energy function:

$$E(c) = \int\int_{\Omega} |\nabla c|^2 dxdy \tag{5}$$

where Ω is the image domain. This energy function can be used for measuring the smoothness of $c(x,y)$. Solving $c(x,y)$ from (3), thus, can be formulated as an energy minimization problem under the constraints of (4), namely

$$\begin{cases} \min\limits_c E(c) = \min\limits_c \int\int_{\Omega} |\nabla c|^2 dxdy \\ s.t. \quad \nabla c(x,y) = \nabla i(x,y), \quad (x,y) \in \Omega^1. \end{cases} \tag{6}$$

Substituting (3) into (6) and noting that $\Omega = \Omega^1 \cup \partial\Omega^1$, $\nabla r(x,y) = 0$, $(x,y) \in \Omega^1$, and l_0 is a constant, we can convert the problem of solving $c(x,y)$ into its dual problem of solving $r(x,y)$. That is

$$\begin{cases} \min\limits_r E(r) = \min\limits_r \int_{\partial\Omega^1} |\nabla(i-r)|^2 ds \\ s.t. \quad \nabla r(x,y) = 0, (x,y) \in \Omega^1. \end{cases} \tag{7}$$

It is worth mentioning that solving $r(x,y)$ is more convenient in comparison with the problem of solving $c(x,y)$, as $r(x,y)$ is piecewise constant and only a finite number of reflectance values need to be determined.

Note that the solution of (7) is not unique. In fact, if $r(x,y)$ is the optimal solution, $r(x,y) + C$ will be either, where C is an arbitrary constant. Such constant can be determined by choosing a point which is not suffered from shading artifact. Generally, this point can be selected as the one which has the maximum intensity in the image.

B. Segmenting Ω^1

As Ω^1 in the constraint conditions is not explicit, the problem (7) cannot yet be solved directly. However, by our assumption, it is followed from (4) that Ω^1 consists of pieces of image regions in which the intensities are constant or change gradually. Thus, we can obtain Ω^1 by using the intensity-based region segmentation techniques, such as region growing, watershed algorithm, etc.

In our experiment, we use an edge-based method followed by a procedure of components labeling for Ω^1 segmentation. The detailed procedures are as follows.

1) Detect edges using a canny edge detector.
2) Perform morphological dilation on the edge map using a 3 $\times$ 3 structuring element.
3) Perform connected components labeling on the dilated edge map.

An example of Ω^1 segmentation is shown in Fig. 1(b), where each region is painted in different colors and the edge pixels of Ω^1 are colored in white.

C. Discrete Solver

Formulating (7) in its discrete domain is straightforward. For each pixel p in Ω, denote N_p the set of its four-connected neighbors which are in Ω, and $\langle p,q \rangle$ a pixel pair such that $q \in N_p$. Let i_p and r_p be the values of image intensity and reflectance at p, respectively. The finite difference discretization of (7) yields the following discrete quadratic optimization problem:

$$\begin{cases} \min\limits_{r|\Omega} \sum\limits_{\langle p,q \rangle \cap \partial\Omega^1 \neq \varnothing} (i_p + r_p - i_q - r_q)^2 \\ s.t. \quad r_p = r_q, \; for \; p,q \subset \Omega_r. \end{cases} \tag{8}$$

The solution of (8) can be obtained by solving its simultaneous linear equations using some well-known iterative solvers, such as Gauss–Seidel iteration, etc. We refer the reader to [12] for more details.

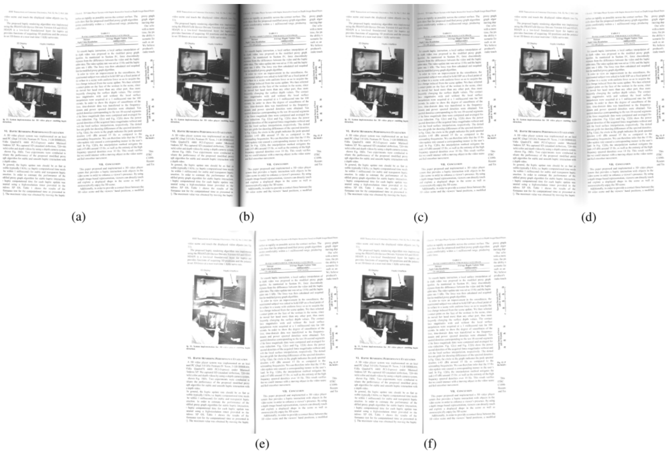

Fig. 2. Comparison results of shading correction on a synthetic shading image. (a) Ground truth image. (b) Synthetic shading image. (c)–(f) Shading corrected images by using Tsoi's method, Brown's method, Zhang's method, and our method, respectively.

D. Smoothing $C(x, y)$ With RBF

Once $r(x, y)$ is calculated, $C(x, y)$ can be obtained immediately from (3). However, the estimation of $C(x, y)$ may contain some noises [see Fig. 1(c)] due to the segmentation errors of Ω^1 or the existence of gradually changed areas in the photographic regions of the image. To deal with this problem, we smooth $C(x, y)$ by using a surface fitting algorithm with radial basis functions (RBF) proposed in [10].

In our experiments, we selected 15×20 collocation points and used Gaussian kernel function $e^{c\|x\|^2}$ for surface smoothing, where c is a prescribed constant. We set $c = 10$ in the experiments. An example of smoothed $C(x, y)$ is shown in Fig. 1(d), and the image after shading correction is shown in Fig. 1(e).

III. Experimental Results

A. Synthetic Results

Fig. 2 shows the comparison results of shading correction on a synthetic shading image. The image [Fig. 2(b)] is created according to (1) by multiplying a ground truth image [Fig. 2(a)] with an illuminance reduction surface $C(\lambda, t)$, given as follows:

$$C(t, \lambda) = (1 - \lambda)g(t) + \lambda g(kt), \quad 0 \le t, \lambda \le 1 \tag{9}$$

where k is a parameter for controlling the aspect ratio of the surface between the top and bottom side, and $g(t) = 1 + \beta(\sqrt{1 - (t-1)^2} - 1)(\beta \in [0, 1])$ is directrix of the surface. In the experiment, we set $k = 0.2$ and $\beta = 0.9$.

We compare our method with Tsoi's method [8], Brown's method [9], and Zhang's method [10]. The corrected images are illustrated in Fig. 2(c)–(f), respectively. As can be observed from the results, Tsoi's method cannot remove shading artifacts at the top and bottom sides of the image simultaneously. Brown's method produces a satisfactory output, but the shading near the spine region is not completely corrected. Zhang's method generates desirable results in the textual regions but fails for the photographic regions, as illustrated in Fig. 2(e). In comparison, our method performs very well in the experiment. It is able to completely correct shading artifacts occurred in the textual or photographic regions.

We also calculate the mean absolute error, error variance, and PSNR between the corrected images and the ground truth image. The results are listed in Table I. As can be observed, our method outperforms the three other methods, no matter which of the above three criteria for performance evaluation is involved.

TABLE I
Comparison Results of Different Methods on a Synthetic Shading Image

	Mean Error	Error Var.	PSNR
Image with shading	15.70	37.29	15.99
Tsoi's method	5.10	12.21	25.70
Brown's method	2.82	7.45	30.11
Zhang's method	9.10	24.74	19.71
Our method	1.24	4.17	35.05

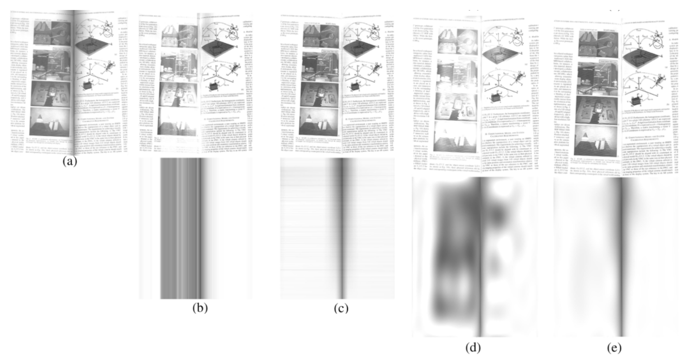

Fig. 3. Comparison results of shading correction on real scanned book image. (a) Image with shading artifacts. (b)–(e) Shading corrected images and the extracted shading images by using Tsoi's method, Brown's method, Zhang's method, and our method, respectively.

B. Real Scanned Book Images

We also tested the proposed method on a variety of real scanned book images. An example is shown in Fig. 3 for illustration purpose. Fig. 3(a) shows the image with nonuniformly distributed shading artifacts. The corrected images and the extracted shading images using different methods are shown in Fig. 3(b)–(e), respectively. Although the ground truth image is not available for the example, the final output image produced by our method is more desirable visually than those of the three other methods.

The running times of the proposed method vary according to image complexity. It takes averagely about 20 s in Matlab to process a scanned book image with 1696×2044 excluding image I/O on a 2.8-GHz Intel Pentium IV PC.

IV. Discussion and Conclusion

The piecewise constant assumption on the reflectance function of the page surface is critical for our implementation. By this assumption, gradually changed areas in the image are simply treated as shading degraded. However, this assumption may wrongly eliminate the gradually changed areas in the photographic regions. We deal with this problem by smoothing the estimated illuminance function with RBF. It works well as such areas in the photographic regions of most scanned book images are generally of small size.

The proposed method will have problems if such areas in the scanned images are dominant or mixed with image shading. In such cases, it is difficult for the method to discriminate shading artifacts from the gradually changed meaningful contents. Incorporating some prior knowledge of the shading or combining some physically-based model with the proposed method may help to well address the problems. We hope better results can be reported in the future.

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