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A unified framework for document restoration using inpainting and shape-from-shading

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ABSTRACT

We present a restoration framework to reduce undesirable distortions in imaged documents. Our framework is based on two components: (1) an image inpainting procedure that can separate non-uniform illumination (and other) artifacts from the printed content and (2) a shape-from-shading (SfS) formulation that can reconstruct the 3D shape of the document's surface. Used either piecewise or in its entirety, this framework can correct a variety of distortions including shading, shadow, ink-bleed, show-through, perspective and geometric distortions, for both camera-imaged and flatbed-imaged documents. Our overall framework is described in detail. In addition, our SfS formulation can be easily modified to target various illumination conditions to suit different real-world applications. Results on images of synthetic and real documents demonstrate the effectiveness of our approach. OCR results are also used to gauge the performance of our approach.

1. Introduction

Document imaging is a fundamental application of computer vision and image processing. The ability to image printed documents has contributed greatly to the creation of vast digital collections now available from libraries and publishers. While traditional document imaging has been performed using flatbed scanning devices, a trend towards more flexible camera-based imaging is also emerging. The goal of document imaging, either via flatbed scanners or digital cameras, is to capture an image that is a reasonable substitute for the original printed content. However, with both approaches unavoidable distortions can be present in the resulting image due to the printed materials' construction (e.g. non-planar), the imaging setup, or environmental conditions, such as non-uniform illumination. Such distortions can make the document difficult to read as well as adversely affect the performance of subsequent processing, namely optical character recognition (OCR) and document layout analysis (DLA).

In this paper, we show how an image inpainting procedure can be combined together with shape-from-shading (SfS) to solve a variety of common distortions found in imaged documents. Our framework is reasonably generic and suitable for use with traditional flatbed scanner imaging as well as less-restrictive camera-based imaging. We demonstrate the effectiveness of our framework on four types of distortions: (1) shading/shadow, (2) ink-bleed and show-through, (3) perspective distortion (from camera-imaged materials) and (4) geometric distortion arising in non-planar documents. Examples of these distortions are shown in Fig. 1. The inpainting routine can be used by itself to address shading and ink-bleed. However, combined with the SfS approach, we can also correct perspective and geometric distortions.

Conference versions of portions of this work have appeared in [1–3]. In this paper, we collate these shorter versions and provide more details to the individual components as well as additional experimental results to demonstrate the effectiveness of our framework. In addition, we have extended the application domain to address various background noise as well as perspective distortions.

Fig. 2 shows an overview of the various components of our system. To correct shading distortions and background noise from ink-bleed and show-through, we first extract a background layer image based on digital inpainting, which is then used to derive the foreground reflectance image based on the notion of intrinsic images. When dealing with documents with ink-bleed, we show how we can tune our edge detector so that the bleed-through pixels are treated as background and thus separated from the foreground stroke pixels.

If the image contains only smooth shading without other background noise or shadows, we can use an RBF-based (radial basis

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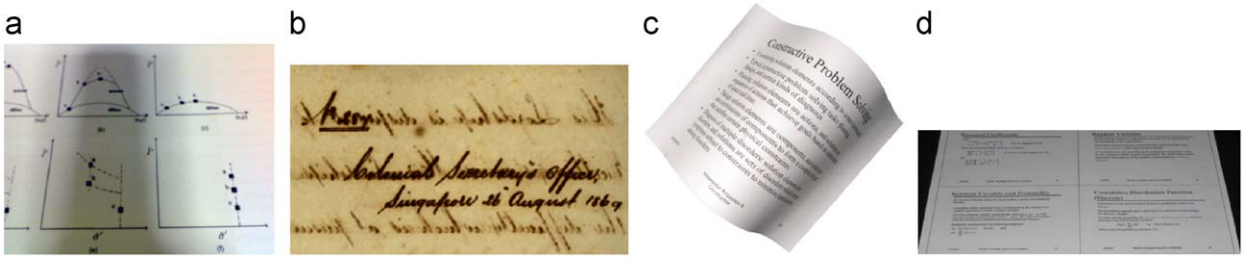

Fig. 1. Document images with (a) shadows; (b) background noise; (c) geometric and shading distortions and (d) perspective distortions.

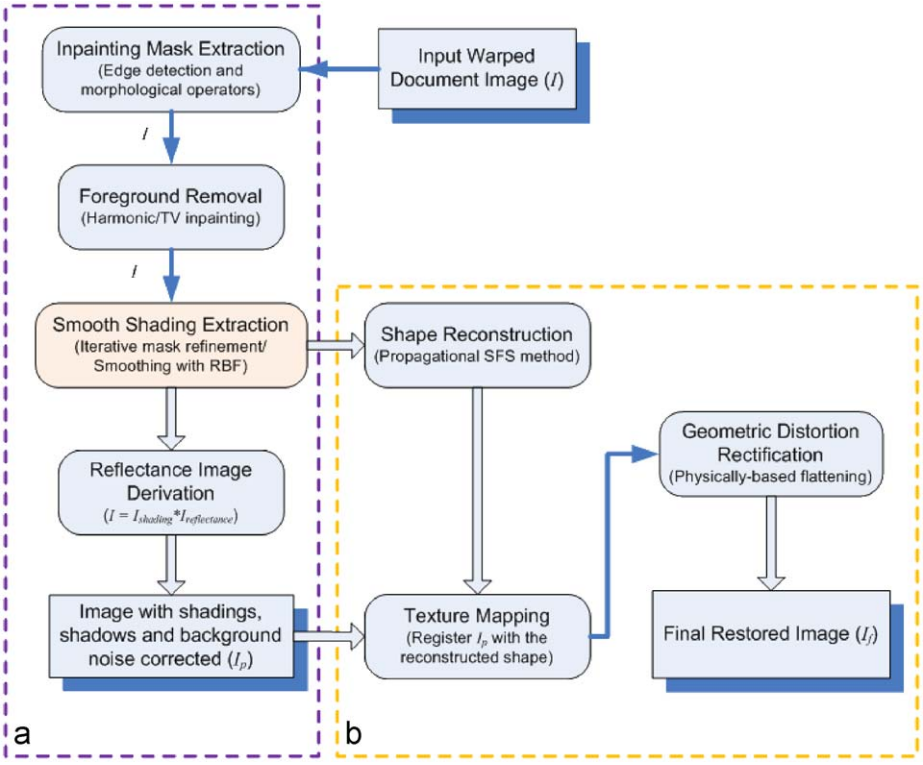

Fig. 2. An overview of the restoration framework for (a) shadings, shadows and background noise and (b) perspective and geometric distortions.

function) smoothing technique to extract a smooth shading image. This shading image can then be used to reconstruct the surface shape of the document based on the SfS methodology. Here we propose a generic SfS method considering the perspective projection model and various lighting conditions. Our SfS is based on a viscosity framework by solving the image irradiance PDE using Lax–Friedrich Hamiltonian and fast sweeping strategy. The geometric distortions are then removed by mapping the 3D surface back to a plane. Since geometric and photometric distortion are often found together, we can use the photometrically corrected image in the geometric correction step and obtain the final corrected image. Compared to our previous framework proposed in [2,3], the current framework extends the application domain to a wider range of distortions including background noise and perspective distortions. Compared to the SfS method proposed in [1], the current method is more generic and more accurate attributing to the additional incorporation of the illumination direction. In addition, more comprehensive experiments and comparisons have been conducted to evaluate the proposed methods with a large set of synthetic and real document images displaying various types of distortions.

1.1. Previous work

Shading distortions in scanned document images can be corrected using binarization techniques such as local thresholding [4], global thresholding [5] or based on the surface shape of the document, typically cylindrical book spines, with the knowledge of the scanner's structure [6]. Shading artifacts in camera-based imaged document are generally more complex especially when they are combined with geometric distortions in arbitrarily warped document images [7]. Boundary interpolation has been used to correct both shadings and geometric distortions on images of warped art materials with isoparametric folding lines [8]. Sun et al. [9] present a system to restore both geometric and photometric artifacts of arbitrarily folded documents by classifying the intensity changes to either illumination changes or reflectance changes based on the notion of intrinsic images [10]. More studies about intrinsic image extraction are done on real-scene images, which treat both shadings and shadows as the illumination intrinsic image and try to separate it from the reflectance image based on color and gradient information [11–14]. Despite all these efforts on deriving the intrinsic images, there is no single exact