Optik 168 (2018) 577–589

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

A robust deblurring algorithm for noisy images with just noticeable blur

Jiazi Huang, Huajun Feng*, Zhihai Xu, Qi Li, Yueting Chen

State Key Lab of Modern Optical Instrumentation, Zhejiang University, Hangzhou, 310027, China

ARTICLE INFO

Article history:
Received 30 June 2017
Received in revised form 14 March 2018
Accepted 11 April 2018

Keywords:
Image deblurring
Just noticeable blur
Image noise
Gradient distribution
Richardson-Lucy algorithm

ABSTRACT

This paper proposes a robust deblurring algorithm for noisy images with just noticeable blur (JNB). Natural images are usually accompanied by JNB and noise when viewed under pixel scale resolution, but are easily neglected. In this paper, we describe the JNB phenomenon and briefly analyze its causes. An image-gradient-related constrained factor is introduced in our algorithm based on the prior of image noise's low gradient distribution. Richardson-Lucy method is also adopted to reduce algorithm's time cost. For large-size cellphone images, we put forward an effective image segmentation model suitable for space-variant blur. Experiments show that our method obtains high-quality deblurring images and are competitive to state-of-the-art deblurring algorithms.

1. Introduction

In image processing, it is always intriguing to obtain a high-resolution image with clear and sharp object boundaries. With the prevalence of high-resolution imaging sensors, images of high quality can be acquired easily. Yet natural images tend to be contaminated by a lot of factors, such as acquisition, processing and compression (like camera shake, object motion, sensor noise, etc). Motion blur, mostly the great 'contribution' to image degradation, which is caused by camera shake or object movement, can be avoided to some extent. Another more intrinsic blurriness exists, however, commonly named as Just Noticeable Blur (JNB) [1]. It is formally defined as blur spanning several pixels and losing certain high frequency information of image structures. JNB seems inevitable in almost every image and small level of noise usually accompanies in this kind of pixel scale. In this paper we focus on non-blind deconvolution problem and propose an effective algorithm for large-size noisy images with JNB.

A number of solutions have been proposed for image deblurring. Image deconvolution aims to obtain a latent clear image from the blurred one, which can be roughly divided into two parts: non-blind deconvolution and blind deconvolution, according to whether the point spread function (PSF) is known. Non-blind deconvolution is an ill-posed problem whose result inevitably suffers from noise and ringing effect. Early methods like direct deconvolution and wiener filtering [2] are simple, yet their unpleasing deblurring results restrict them from being widely used(wiener filtering is in fact an improved version of direct deconvolution). Richarson-Lucy (RL) algorithm [3] is also a classic method that yields a relatively effective result, but the side-effect of noise is still a problem. In 2007 Y. Wang et al. proposed an algorithmic framework FTVD for numerical de-convolution with various total variation regularizations [4]. FTVD can be regarded as one of the best TV regularization methods so far in preserving edges and object boundaries. The key point of FTVD method lies in solving the

* Corresponding author.
E-mail address: fenghj@zju.edu.cn (H. Feng).

https://doi.org/10.1016/j.ijleo.2018.04.052

(a) (b) (c)

Fig. 1. (a) an example of image JNB captured by a cellphone camera; (b) close-up; (c) close-up.

basic total variation (TV) model that does not require any modification to non-differentiable term. The method is fast and proves effective for real image deblurring. However, it did not consider the impact of noise gradient when dealing with the non-differentiable term. As for blind-deconvolution, it is an ill-posed problem in which the latent image and the PSF are both needed to be estimated during deblurring. Recent progress has been made, representative algorithms [5–12] have been designed to require a clear image from a blurred one. L. Xu and J. Jia [10] proposed a two-phase kernel estimation method for motion deblurring which took into consideration of image spatial prior and then employed TV-L1 model for later deconvolution step. J. Pan et al. [12] utilized image intensity as well as gradient and developed a L0-regularized prior. This debluring method is then extended from processing text images to natural images with complex scenes, low illumination and non-uniform deblurring. However, for the case when blurred images are polluted by unpleasant noise, neither of the above methods obtain satisfactory results.

In this paper we deal with large-size natural images with slight blurriness and noise, captured by cellphone cameras. Our experiments show that the JNB which varies roughly from 2 to 5 pixels, is space-variant: the blur size of field edge is generally a bit larger than that of field center. Based on the above result and the consideration of time cost, we put forward a segmentation framework that divides an image into smaller image blocks, each of which the kernel may be different. For each image block, our deblurring algorithm is adopted to recover a clear result. The main contribution of our work is the introduction of an image-gradient-related constrained factor to deconvolution. This helps to preserve sharp discontinuities and suppress noise as well as artifacts during deblurring, on the basis of the fact that noise and object boundaries differ in image gradient features. Tikhonov regularization is also introduced to better suppress noise. Furthermore, we creatively employ RL algorithm to obtain a relatively clear result as a prior input for the following deblurring step, which is achieved through an alternating-minimization scheme. This accelerates algorithm's running speed and also slightly improves image sharpness. We demonstrate our algorithm by presenting the deblurring results of both simulated degraded images and real natural ones. Also, comparisons with the state-of-the-art methods have been made, showing that our restored images are of high quality.

2. Noisy images with JNB

The concept of JNB is usually mentioned in the field of image quality analysis [13–16]. It results from the notion of "just noticeable difference" (JND) whose definition is the minimum amount by which a stimulus intensity must be changed relative to a background intensity in order to produce a noticeable variation in sensory experience [15]. Given a contrast higher than the JND, the JNB idea is introduced as the minimum amount of perceived blurriness around an edge [16]. In Ref. [1], JNB is defined as blur spanning several pixels and losing a quantitatively insignificant level of image structures.

JNB is commonly seen in natural images, especially those taken by cellphone cameras. For most cellphone imaging systems, minor blur caused by light diffraction is almost inevitable, since the aperture and CMOS sensor are restricted by their sizes. The diffraction blur is barely noticeable, usually spanning one or two pixels when viewed at maximum resolution. The design defect of optical imaging systems also contributes to image JNB, causing larger blurriness. It is quite common that the blurriness in image center is greater than that in the edge. When processing JNB images, noise becomes an unnegligible problem, though it may not be obvious if not viewed under pixel-scale resolution. The noise is usually caused by imaging sensors, image compression processing, etc. Fig. 1 shows a typical example of natural noisy images with JNB and its close-ups. The image is captured by a cellphone camera, and a tripod is used to avoid unnecessary blurriness. When the image's viewed in its original resolution, unsatisfactory details including slight blurriness and noise can be found.

3. Proposed algorithm

3.1. Image segmentation and kernel estimation

Considering that the blurriness varies in different image fields, it is not appropriate to adopt a space-invariant kernel for the whole image which may introduce side-effects like ringing effect due to inconsistent kernels [7]. Therefore we decide to