Information Sciences 281 (2014) 736–749

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Single-image motion deblurring using an adaptive image prior

Ning He [a,*], Ke Lu [b], Bing-Kun Bao [c], Lu-Lu Zhang [a], Jin-Bao Wang [a]

[a] Beijing Key Laboratory of Information Service Engineering, College of Information Technology, Beijing Union University, Beijing 100101, China
[b] University of Chinese Academy of Sciences, Beijing 100049, China
[c] Institute of Automation, Chinese Academy of Sciences, Beijing 100080, China

ARTICLE INFO

Article history:
Received 23 February 2013
Received in revised form 27 March 2014
Accepted 8 April 2014
Available online 9 May 2014

Keywords:
Motion deblurring
Point spread function
Adapting image prior
Spatially varying motion

ABSTRACT

Blind deblurring is the restoration of a sharp image from a blurred image when the blur kernel is unknown. Most image deblurring algorithms impose a uniform sparse gradient prior on the whole image, and reconstruct the image with piecewise smooth characteristics. Although the sparse gradient prior removes ringing and noise artifacts, it inevitably removes mid-frequency structures, leading to poor visual quality. The gradient profile of fractal-like structures is close to a Gaussian distribution, and small gradients from such regions are severely penalized by the sparse gradient prior. In this paper, we introduce an image deblurring algorithm that adapts the image prior to the underlying detailed structures. The statistics of a local detailed structure can be different from those of the global structure. By identifying the correct image prior for each pixel in the image, our approach models the spatially varying motion blur exhibited by camera motion more effectively than conventional methods based on space-invariant blur kernels. Using different priors for the local region and the motion blur kernel, we derive a minimization energy function that alternates between blur kernel estimation and deblurring image restoration until convergence. Experimental results demonstrate that the proposed approach is efficient and effective in reducing motion blur in an arbitrary direction in a single image.

1. Introduction

Motion deblurring is a challenging task in the fields of computer vision and image processing, and is a prime cause of poor quality in digital photography. The increasing popularity of domestic digital cameras, which have become too small to hold sufficiently steady, has seen motion blur caused by camera shake become commonplace. Thus, there is a need for motion deblurring technology that restores a clear (sharp) image from motion-blurred (observed) images. Given only a single image, blur removal is known to be a blind deconvolution problem, i.e., it requires the simultaneous recovery of both the blur kernel and the sharp image with the blurred image as the input. Motion blur is characterized by its blur kernel, referred to as the point spread function (PSF), which is closely related to the motion.

A common assumption in existing motion deblurring algorithms is that the motion PSF is spatially invariant, reducing the set of camera motions that may be modeled. This implies that all pixels are convolved with the same motion blur kernel. Under this assumption, the blur kernel and latent image estimation can be formulated as a maximum-a posteriori (MAP) framework and regularized by a variety of priors, as blind deconvolution is a highly ill-posed problem. The MAP framework,

* Corresponding author. Tel.: +86 13811156835.
E-mail addresses: xxthening@buu.edu.cn (N. He), luk@ucas.ac.cn (K. Lu), bingkunbao@gmail.com (B.-K. Bao).

http://dx.doi.org/10.1016/j.ins.2014.04.009
0020-0255/

which is converted into a convex formulation, alternately optimizes the blur kernel and the latent sharp image until some convergence criterion is reached. There are two drawbacks to this formulation. First, although convolution can be computed quickly using fast Fourier transforms (FFTs), the alternating optimization remains a slow process. Second, as the problem is highly ill-posed, there is no guarantee that the blur kernel and the latent sharp image have been correctly estimated from just a single blurred image.

As recently discussed by Levin et al. [26], the abovementioned global PSF assumption is typically violated, as it is only valid for limited camera motions. Fig. 1 shows a motion-blurred photograph in which the blur kernel is not spatially uniform. Levin et al. [26] advocated the need to model camera motions that are more general, as these are quite common and can cause spatially varying blur.

In this paper, we address this issue by proposing a new and compact motion blur model that uses image priors and describes spatially varying motion. In our approach, we first adapt the image prior to the underlying detailed structures. The blur kernel is then estimated from the input region using a small-scale L_1-norm optimization without employing alternating optimization. A high-quality latent sharp image can then be estimated using a state-of-the-art non-blind motion deblurring method.

The main contribution of our work is that we consider the local image prior and adapt it by introducing an L_1 sparse constraint, a binary feature constraint, and local smoothing. The L_1 sparse characteristic of the blur kernel is consistent with the analysis of the motion blur kernel. Levin et al. proposed a non-blind deblurring model using natural image statistics to alleviate the ringing artifacts in the deblurred image [27], and proposed an iterative reweighted least-squares method to solve the sparsity-constrained least-squares problem. This model was further generalized by Cho et al. [14], who adapted the sparseness according to the image content using a learned regression model. Cai et al. proposed a blind motion deblurring method by exploiting the sparseness of natural images in over-complete frames, such as curvelets, to help with kernel estimation and sharp image estimation [6]. By integrating all these aspects into a regression framework [14], we formulate an energy function that should be minimized alternately between blur kernel estimation and deblurred image restoration.

The rest of this paper is organized as follows. In Section 2, we review previous work in this area. Section 3 introduces the motivation behind our work, and the proposed approach to motion deblurring is presented in Section 4. We describe the results of our approach in Section 5, and conclude the paper with a discussion and ideas for future work in Section 6.

2. Related work

Previous work targeting image blur owing to camera shake has assumed a global PSF for the entire image. This approach can be further divided into non-blind and blind cases. In the non-blind case, the motion blur kernel is assumed to be known or can be computed elsewhere. Classical algorithms such as Richardson–Lucy (RL) deconvolution [29] and Wiener filtering [46] can be applied to this kind of problem. Research addressing image deblurring, including camera shake and other types of blur, target either blur kernel estimation, regularization of the final result, or both. For example, Danielyan et al. [17] and Chan and Shen [10] employed total variation regularization to help ameliorate ringing and noise artifacts. Donatelli et al. [18] used a PDE-based model to recover a sharp image with reduced ringing by incorporating an anti-reflective boundary condition and a re-blurring step. Following the development of PDE methods, many deblurring techniques based on the

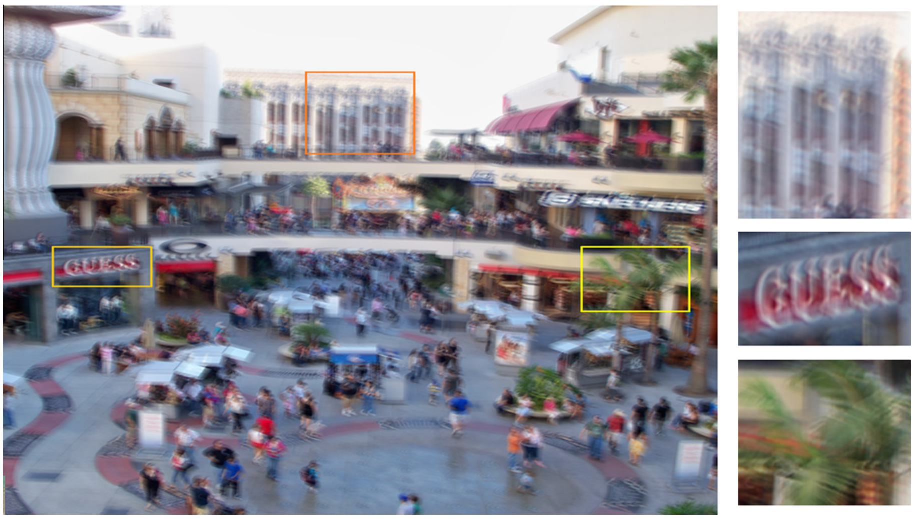

Fig. 1. This example demonstrates the spatially varying nature of camera shake. Left: blurry image. Right: close-ups of different parts of the image.