An Efficient Method for Projection-Based Image Deblurring

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Abstract
Previously lot of problems are encountered in image processing – image deblurring. From the origination of the image deblurring to its broad applications in enormous number of areas today, the deblurring approaches have evolved with time and forked into many different and fascinating branches. In this paper, we propose a method for reducing out-of-focus blur caused by projector projection. We estimate the Point-Spread-Function (PSF) in the image projected onto the screen by using a camera that captures the projector screen. According to the estimated PSF, the original image is pre-corrected, so that the projected image can be deblurred. Proposed system can successfully reduce the effects of out-of-focus projection blur, even though the screen image includes spatially varying blur without projecting the feature image.

Keywords
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I. Introduction

In 1950s and early 1960s, the cold war between the United States and the former Soviet Union brought heated competitions in their space programs which gave birth to the field of image deblurring. At that time, the image deblurring processes were mainly concentrating on producing pictures of Earth and our solar system. In the mean time, the extreme need for obtaining essential and important information from astronomical images, and ultimately the need for universal and systematic image restoration techniques were brought to the engineering community, for the first time. Enormous number of algorithms, following these increasing needs in astronomy and many others, found their way into the era of the so called digital image deblurring.

Image restoration, especially image deblurring, has been used in many other applications as well. For instance, it has been used to restore blurry X-ray images of aircraft wings to improve federal aviation inspection procedures. It is used for restoring uniformly blurred television pictures. Moreover, it has applications in analyzing images of unique events such as satellite photographs, medical spiral CT images, images of biological tissues, and electron microscopy images coming from scientific experiments.

Augmented Reality (AR) and Mixed Reality (MR) are techniques for overlaying virtual objects onto a real world. AR has recently been applied to many kinds of applications including entertainment. In traditional AR applications, LCD displays and HMDs are generally used as output device. This type AR is called Projection Based AR. The projector is used for various usages, but can be used in limited environments. The projector basically needs to project onto non-textured and non-colored planar screen, which should be perpendicular to the projection direction. To reduce such limitation for using projectors, a lot of methods have been proposed. Most research project feature images for measuring the display's geometric information, display's and environmental radiometric information. Applying these methods to Projection Based AR make displayed image more realistic.

Image deblurring is a widely existing problem in image formation process, due to the imperfection of the imaging devices and remains an active research area in image processing communities. Possible factors causing the blur are atmospheric turbulence (in astronomy), defocusing, as well as the relative motion between camera and the scene.

In this paper, to achieve Projection Based AR that can be used in case of moving display object, we propose a new method that reduces out-of-focus blur on the projected display without projecting the feature image. We use the original image that should be displayed to the observers as projected image for estimating the degree of out-of-focus blur and the geometrical skew. In order to adapt the projector's slanted pose to the screen, we can also reduce gradually changing out-of-focus projection blur by using a camera to estimate a series of spatially varying degrees of blur. Then we pre-correct the original image by Wiener Filtering according to the estimated blur before projection.

II. Related Work

Cai et al. proposed a blind motion deblurring method by exploiting the sparseness of natural images in over-complete frames, such as curvelet, to help with kernel estimation and sharp image estimation. Based on compressive sensing theory, Yang et al. assumes that the same sparse representation coefficients are shared for the high resolution and low resolution patches with respect to a high-resolution dictionary and a corresponding low-resolution dictionary, respectively. This method has been shown to generate state-of-the-art results for image super resolution. For blind image deblurring, however, this method cannot be applied directly, due the unknown blurring kernel (PSF), thus the construction of the coupled dictionary is not an easy task. Very recently, Hu et al. proposed to construct the blurry-sharp dictionary couple via the blurry image and deblurred image using the current estimation of the kernel. However, as the deblurring procedure will usually introduce severe artifacts, the dictionary pair constructed via this method is not desirable for deblurring.

To date, methods employed in single image deblurring can be classified into two main categories: blind and non-blind deconvolution. In this subset of blind deconvolution, there are also two main kinds of approaches: First one is a separated approach. This approach estimates the PSF and the true image as two successive but separated procedures. This approach basically estimate the PSF first from all information that the recorded image provides, and in the later step, it uses the estimated PSF to restore the original image. Then in the second step, one can use one of many non-blind deconvolution algorithms since the kernel is already known. Second approach is to combine the estimation of PSF and the true image together as a merging task. This approach can simultaneously identify both the blur kernel PSF and the image itself. This usually leads to more complex algorithms.

A. A Priori Blur Identification Methods

This is a general class of approaches that belong to the separated approaches we mentioned above. It assumes some basic characteristics of the PSF and determine the PSF based on these assumptions first. These assumptions include the symmetry of the PSF, or some specific form of PSF, as discussed in the blur models part. The good aspects about a priori blur identification class of methods are that they are simplest class of blind deconvolution methods to implement. And they are computational less demanding. When there is some information about the PSF such as there are special features of the true image or the PSF has some fixed form like one dimensional motion blur model, these approaches would be a good choice. For more general situations or less information available, it might be better to consider other approaches.

B. Zero Sheet Separation Algorithm

This algorithm is first developed by Lane and Bates. Using the zero sheets concept, it has been shown later that if the image or the Fourier amplitude is measured at the Nyquist rate, the image processing in more than two dimensions is an over-determined problem, whichmay have contradicting solutions. The advantages about zero sheet algorithm is that it can be used to simultaneously deconvolve more than two components. It can also determine how many irreducible component signals the original signal has. However, themethod has many practical disadvantages, two of which are first, the algorithm is highly sensitive to noise, and second, the algorithm is prone to numerical instability for large data sets.

III. Image Blurring and Deblurring

The out-of-focus blur can be represented as below, where a blurred image g(x, y) is made as a result of convolution of PSF h(x, y) and an original image f (x, y).

f (x, y)* h(x, y) = g(x, y)

There are two typical way of modeling the out-of-focus PSF. One is the Disk type PSF, and another is the Gaussian type PSF. We assume out-of-focus projection blur as a circular Disk PSF with radius r of the form.

$$h(x,y)=\begin{cases}1 & \sqrt{x^2+y^2}\le r\\ 0 & \sqrt{x^2+y^2}\ge r\end{cases}$$

In the same way, a deblurred image f~ (x, y) is a result of deconvolution of PSF and the blurred image.

f~ (x, y) = g(x, y)* h^{-1} (x, y)

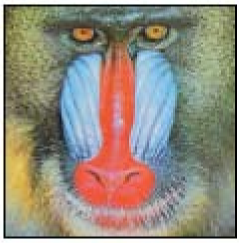
IV. Proposed Scheme

When we use a projector located at a slanted pose to a screen, non-vertical projection makes the displayed image on the screen partially blurred. We can represent this out-of-focus projection blur with the PSF. We use a camera to estimate a PSF on a screen. First, we project an image on the screen by the projector, and then capture a displayed image on the screen by the camera. Here we have two images, one is what we would like to project onto the screen (an original image), and another is what the camera captures the displayed image on the screen (a captured image). In the case of a vertical projection to the screen, all of the regions are uniformly blurred. In the case of the projection slanted to the screen, blur on the screen is not uniform. To apply the case of the slanted projection blur, we divide these two images into small regions, and then estimate a series of spatially varying PSFs of blur in the captured image, by comparing these images. Then we pre-correct each sub-image by Wiener filtering according to the estimated PSF before projection.

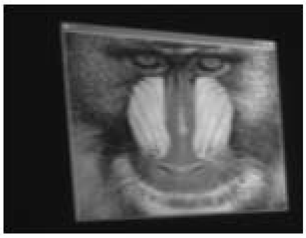
A. Pre-Processing

We estimate the PSF by comparing the original image with the captured image, but the captured image is skewed to the screen surface by the slanted projection. A pixel in the captured image xc is converted to a pixel in the projected image xp using Homography H_{cp} as

$x_p = H_{cp}\, x_c$



(a)Original image



(b)Projected

Fig. 1: Difference of Original and Captured

To calculate the Homography, we need at least 4 corresponding points. We capture feature rectangle image (Fig. 1(a)) projected onto the screen, and calculate Homography using these two images. The captured image (Fig. 1(b)) is converted using Hcp as Fig. 2.

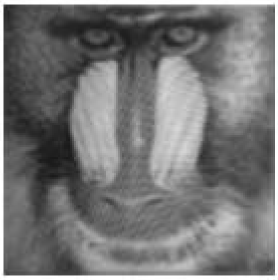


Fig. 2: Converted Image Using Homography

Now we will discuss about how to estimate PSF from only the blurred image. In the case of projector blur, there are two images, the blurred image and the original image. So we can estimate PSF by comparing these two images. Taking account into the slanted projection case, we estimate a series of spatially varying PSFs of blur in the captured image.

- First we divide the original image and the captured image into small region.
- Second we generate multiple images with different PSF's parameters from the original image by increasing the parameter r = 1.0, 2.0,…
- Then we calculate NCCs (Normalized Cross Correlation) between every blurred image g r (x y) , and the captured image g(x, y).

We estimate the PSF's parameter on the captured image as the comparison image's parameter that has highest NCC.

$$R_{NCC}=\frac{\sum_{y=0}^{N-1}\sum_{x=0}^{M-1}\left(g(x,y)-g_r(x,y)\right)}{\sqrt{\sum_{y=0}^{N-1}\sum_{x=0}^{M-1}g^2(x,y)\sum_{y=0}^{N-1}\sum_{x=0}^{M-1}g_r^{\,2}(x,y)}}$$

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B. Pre-Correction

We make i × j pre-corrected sub-images f~ ij by applying the Wiener Filter with estimated PSFs to the original image f ij. Applying this Wiener Filtering to all divided sub-images, we make the pre-corrected image f ~.

(a). Original image

(b). Pre-Corrected Image

Fig. 3: Pre-Correction with Cutting Normalization

By applying the Wiener Filter to the original image as shown in fig 3, the output image includes negative values and higher values than the maximum value of the original image (i.e.255). Since the projector can project the image with the pixel value within the range of 0~255, we have to normalize the output image, so that the range of values of the output image can be fit to the range of projected image.

V. Performance

Proposed method first estimate PSFs from an image and a captured image and then pre-correct the image using estimated PSFs. Brown's method means that first estimate PSFs from an rectangle image and a captured image and then pre-correct the animal image using most in-focus region as an exemplar region.

(a). Original image

(b). Browns image

(c). Proposed Method Image

Comparing the above images, all region of the pre-corrected image by proposed method is sharper than the original image. On the other hand, the pre-corrected by Brown's method has both corrected region and non-corrected region. Non-corrected region is referring to the exemplar region and the degree of correction is less than that of our proposed method. image. These results confirmed that the result of proposed method has most close to the original image, especially in the texture of image surface.

VI. Conclusion

In this paper, to achieve Projection Based AR that can be used in case of moving display object, we propose a new method that reduces out-of-focus blur on the projected display without projecting the feature image. We use the original image that should be displayed to the observers as projected image for estimating the degree of out-of-focus blur and the geometrical skew. In order to adapt the projector's slanted pose to the screen, we can also reduce gradually changing out-of-focus projection blur by using a camera to estimate a series of spatially varying degrees of blur. Then we pre-correct the original image by Wiener Filtering according to the estimated blur before projection.

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