論文の内容の要旨

SINGLE-SHOT IMAGE DEBLURRING WITH MODIFIED CAMERA OPTICS
（カメラ光学系の加工による単一画像からのボケの除去）

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The recent rapid popularization of digital cameras allows people to capture a large number of digital photographs easily, and this situation makes automatic avoidance and correction of ``failure'' photographs important. While exposure and color issues have been mostly resolved by the improvement in automatic corrective functions of cameras, defocus, motion, and camera shake blurs can be handled only in a limited fashion by current cameras. Camera shake blurs can be alleviated by an anti-camera shake mechanism installed in most cameras; but for focus, although a particular scene depth can be focused with an auto-focus function, objects at different depths cannot be captured sharply at the same time. Moreover, defocused images can often result due to the failure of auto-focusing. In addition, blurs caused by object motion, i.e., motion blurs, are only avoided by increasing the shutter speed and sensor sensitivity when cameras detect motions in a scene.

This dissertation proposes a method for removing defocus and motion blurs for digital cameras. Since deblurring is generally an ill-posed problem, and hence an image processing approach alone has limitations, the proposed method includes modifications of camera optics. In this regard, this dissertation pursues low cost implementation, aiming at applications to consumer products. That is, small modifications to existing cameras or mechanisms that can be directly derived from existing ones will be adopted.

For removal of defocus blurs, a method is proposed for estimating the defocus blur size in each image region by placing red, green, and blue color filters in a camera lens aperture. As captured image will have depth-dependent color misalignment, the scene depth can be estimated by solving a stereo correspondence problem between images recorded with different wavelengths. The depth is directly related to the defocus blur size, and deblurred images can be produced by deconvolving each region with the estimated blur size. The modification requires only inexpensive color filters.

For motion blur removal, this dissertation proposes to move the camera image sensor circularly about the optical axis during exposure, so that the attenuation of high frequency image content due to motion blur can be prevented, facilitating deconvolution. The proposed method may be implemented using a sensor-shift system of an anti-camera shake mechanism. The frequency domain analysis of the circular sensor motion trajectory in space-time shows that the degradation of image quality is equally reduced for all objects moving in arbitrary directions with constant velocities up to some predetermined maximum speed.

Moreover, this dissertation proposes a method for speeding up deconvolution computation for efficient deblurring. Deconvolution quality is known to be improved by taking into account derivative distributions of natural images. While existing methods take time to repeat derivative and convolution operations, the proposed method achieves similar image quality with 1/10 computation time by taking derivatives beforehand and by working in the gradient domain.

In addition, a set of intuitive user interfaces are provided with which the user can interactively change the focus settings of photographs after they are captured, so that she/he can not only obtain an all-in-focus image but also create images focused to different depths. In the case where only photographs captured with conventional cameras are available, the proposed interface provides the means to estimate blur in a user-assisted manner.