Blind Optical Aberration Correction by Exploring Geometric and Visual Priors

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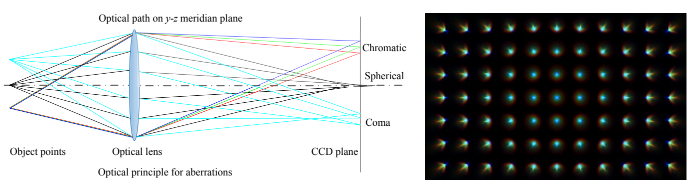
Optical aberration is one of the most common causes of image degeneration that affects almost all lens-based imaging systems. Researchers have also proposed various complex hardware solutions for compensating optical aberration [6], but the requirement of using special devices limits their application range, especially for consumer applications. Similarly, the requirement of beforehand calibration also limits the application of the *non-blind* computational aberration correction methods[1, 3, 5]. Therefore, the more challenging problem, i.e. blindly correcting the aberration, is in demand.

This paper provide a blind aberration correction method that achieves higher quality and better robustness/flexibility than previous approaches[2, 4]. Specifically, we first investigate the principle of optics and derive the geometric priors of the PSFs, including both the global rotational symmetry and the local reflectional/central symmetry. The radial splitting and warping framework as well as the unified local symmetry constraint are proposed. Then, inspired by the observation that in an optically aberrated image, sharpness varies spatially as well as across color channel, we propose to conduct both kernel estimation and deconvolution in a sharp-to-blur order. Specifically, we restore the sharpest channel and local region first, and then use the result to guide the processing of other regions and channels.



(a) (b)

Figure 1: The principle of optical aberrations (a) and the resulting PSFs (b).

Geometric Priors. Fig. 1(a) shows the light paths, and the resulted global and local symmetric PSFs.

Because of the global symmetric, the pixels in a narrow ring region have roughly the same PSF with different rotations. If we rotate the local patch of all pixels properly, the PSFs become uniform. By decomposing the image plane into a series of concentric ring regions, and further warping them into rectangular subimages, the non-uniform aberration becomes uniform in these rectangle subimages, as shown in Fig. 2.

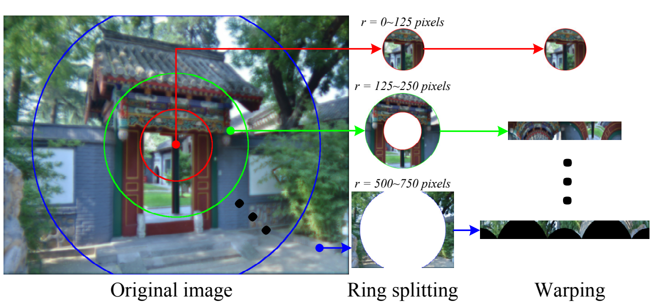


Figure 2: The proposed concentric ringwise splitting and warping.

To handel the local symmetry of PSFs, we formulate these two symmetry constraints in a unified mathematical term. The basic idea is to divide the PSFs into sets according to the specific type of symmetry, and then minimize the summation of intra-set variances. Mathematically it is defined as:

$$\mathcal{C}^k_{sym}(\mathbf{K}) = \lambda_s \sum_j \sum_{i \in \mathbb{S}_j} \left(\mathbf{K}(i) - \frac{1}{|\mathbb{S}_j|} \sum_{m \in \mathbb{S}_j} \mathbf{K}(m)\right)^2, \tag{1}$$

This is an extended abstract. The full paper is available at the Computer Vision Foundation webpage.

where $\mathbf{K}$ denotes the PSF, j indexes the sets $\mathbb{S}_j$ whose size is $|\mathbb{S}_j|$, and i is the index of the elements in a set. The weight of symmetry constraint λ_s is set to be 20 in this paper.

Visual Priors. Intuitively, it is easier to restore a sharper image than a more blurry one by blind deconvolution. Therefore, we propose a sharp-to-blur strategy for lens aberration removal, which consists of two main information propagation directions:

(1) Restore the sharpest channel first, and then use it as the reference channel to restore the other ones. For the sharpness channel $ch = sc$, we set $\mathcal{C}_{sc}(\mathbf{L}_{p,sc}) = \lambda_l ||\nabla \mathbf{L}_{p,sc}||_1$ as the smoothness constraint in deconvolution ($\mathbf{L}_p$ denotes the latent sharp image patch p). For other channels (i.e. $ch \neq sc$), the result of the sharpest channel is used as a reference for restoration as:

$$\mathcal{C}_{ch}(\mathbf{L}_{p,ch}) = \lambda_l ||\nabla \mathbf{L}_{p,ch}||_1 + \lambda_{ch} ||\nabla \mathbf{L}_{p,ch} - \nabla \mathbf{L}_{p,ref}||, \tag{2}$$

where $\nabla \mathbf{L}_{p,ref}$ is the scaled gradient map of the sharpest channel.

(2) Use the transformed version of the PSF computed from the previous sharper patch as the reference for the current patch, which leads to the following energy term:

$$\mathcal{C}^k_{adj}(\mathbf{K}) = \sum_p \lambda^{k_p}_{adj} ||\mathbf{K}_p - \mathcal{T}_{p-1 \to p} \cdot \mathbf{K}_{p-1}||^2, \tag{3}$$

where $\mathcal{T}_{p-1 \to p}$ is the transformation between adjacent PSFs.

Incorporating both the geometric and visual priors, our final objective function for aberration removal is:

$$E = \sum_p \{\, ||\mathbf{L}_p * \mathbf{K}_p - \mathbf{B}_p||^2 + \mathcal{C}^l_{ch}(\mathbf{L}_p) + \mathcal{C}^k_{sym}(\mathbf{K}_p) + \mathcal{C}^{k_p}_{adj}(\mathbf{K}_p, \mathbf{K}_{p-1}) \,\}, \tag{4}$$

where $\mathbf{B}_p$ and $\mathbf{L}_p$ are the observed and restored image patch p. The details for optimizing this objective function can be found in our full paper, and the result on a synethtics image is shown in Fig. 3.

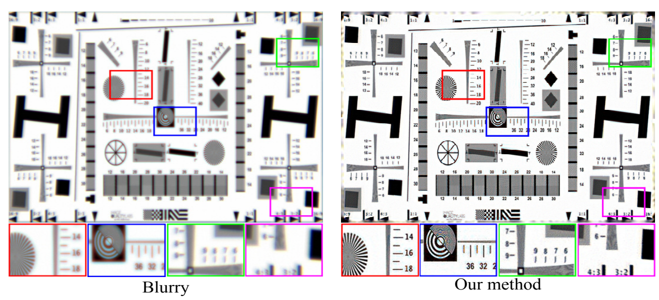


Figure 3: The experiment result of the proposed method.

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