Coded Aperture Projection

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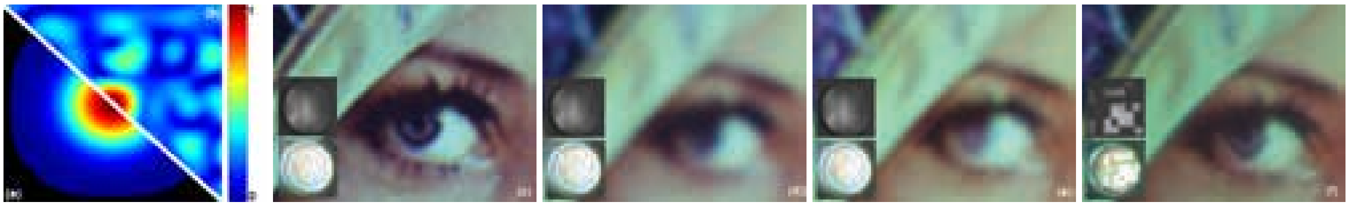

Figure 1: *The power spectra of a Gaussian PSF (a) and of the PSF of a coded aperture (b): Fourier magnitudes that are too low are clipped (black), which causes ringing artifacts. Image projected in focus (c), and with the same optical defocus (approx. 2m distance to focal plane) in three different ways: with spherical aperture – untreated (b) and deconvolved with Gaussian PSF (e), with coded aperture and deconvolved with PSF of aperture code (f). The sub-images in c-f are photographs of the apertures and their captured PSFs.*

Abstract

We integrate coded apertures into off-the-shelf projectors to increase their focal depth. The regional defocus of the projection on the surface is measured automatically. The projected images are then deconvolved with locally scaled aperture codes. This leads to significantly better results than deconvolving with Gaussians in cases where regular spherical apertures are used.

Keywords: Projector-camera systems, defocus compensation, coded apertures, inverse filtering, deconvolution.

1 Introduction and Motivation

Coded aperture imaging has been presented recently in the context of computational photography. In contrast to conventional apertures, coded apertures enable –for instance– re-focussing captured images after they have been taken. Video projectors apply simple spherical apertures and suffer from a relatively short focal depth. This is problematic when images are projected onto non-planar surfaces, such as in case of spherical or cylindrical projection displays. They might be regionally defocussed if the aperture of the projector is too large. Using smaller apertures for increasing the focal depth, however, decreases the light throughput. Several approaches exist that increase projected focal depth digitally by convolving the projected images with the inverse blur function (e.g., [Brown et al. 2006]). The Gaussian point-spread function (PSF) of regular spherical apertures, however, sets clear limitations in terms of recovering fine image details. We show that deconvolution with coded apertures leads to the reconstruction of significantly more image details.

2 Technical Approach

In computer vision, optical defocus is often described as convolution with a filter kernel that corresponds to an image of the aperture being used by the imaging device. The degree of defocus correlates to the scale of the kernel. Convolving an image with the inverse aperture kernel will digitally sharpen the image and consequently compensate optical defocus. This is referred to as deconvolution or inverse filtering. In frequency domain, the reciprocal of the filter kernel is its inverse, and deconvolution reduces to a division. Low magnitudes in the Fourier transform of the aperture image, however, lead to intensity values in spatial domain that exceed the displayable range. Therefore, the corresponding frequencies are not considered, which then results in visible ringing artifacts in the final projection. This is the main limitation of previous approaches, since in frequency domain the Gaussian PSF of spherical apertures does contain a large fraction of low Fourier magnitudes (cf. figure 1a). Applying only small kernel scales will reduce the number of low Fourier magnitudes (and consequently the ringing artifacts) – but will also lead only to minor focus improvements (cf. figure 1d). To overcome this problem, we apply a coded aperture whose Fourier transform has initially less low magnitudes (cf. figure 1b). Consequently, more frequencies are retained and more image details are reconstructed (cf. figure 1d).

3 Implementation and Future Work

We apply the momentum preserving principle used in [Bimber and Emmerling 2006] for measuring the local defocus of the projector on a non-trivial surface. This leads to relative defocus values for each projector pixel, which are normalized to a discrete number of (15 in our case) aperture scales, whereby the smallest defocus pixel is assumed to be optically focussed and correlates to scale 0. The original image as well as the 15 scaled aperture images are Fourier transformed. Deconvolution is carried out for all scales in frequency domain and the results are transformed back to spatial domain. A final compensation image is composed on a per-pixel basis from all 15 results depending on each pixel's measured defocus. All operations (Fourier transformations, deconvolution and composition) are carried out on the GPU and require less than 3 seconds. Currently we are working on a faster implementation to reach real-time compensation rates, and on the investigation of optimized code patterns.

References

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