Adaptive Coded Aperture Projection

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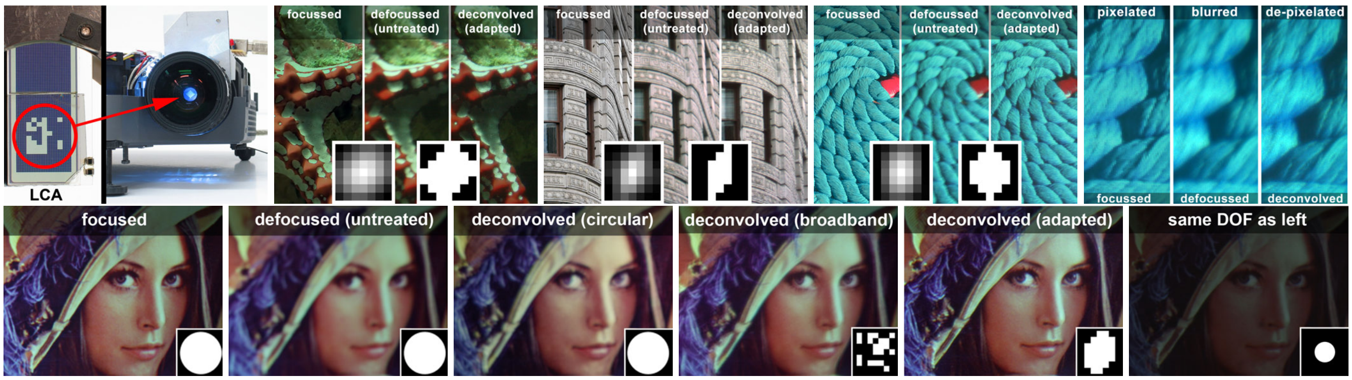

Figure 1: *Placing a transparent liquid crystal array at the aperture plane of a projector lens allows encoding the aperture's mask pattern dynamically – depending on the perceivable frequencies of the displayed images. Such adaptive coded apertures significantly improve depth-of-field through inverse filtering when compared to static circular aperture stops or broadband masks. They can also be applied for high quality projector de-pixelation and for increasing the temporal contrast of video sequences in a similar way as auto-iris projection lenses. The inlays illustrate the computed intensity codes and the applied binary masks. All images displayed with an adaptive coded aperture are perception optimized and have been computed for the given viewing conditions (50 cm distance to screen, displayed at a diagonal of 20 cm / 10 cm for top row / bottom row). Possible artifacts can only be perceived when observing the images at closer distances or larger sizes. The bottom row illustrates a comparison of adaptive apertures with various static (circular and broadband) ones. While the five images on the bottom-left are adjusted to a similar brightness to enable a better comparison of focus, the lower right image is captured using the same exposure as the image left to it. A small circular aperture has been applied that achieves the same depth-of-field as with the binarized adaptive coded aperture at the cost of a significant loss of brightness.*

With adaptive coded aperture projection, we present solutions for taking projectors to the next level. By placing a programmable liquid crystal array at a projectors aperture plane we show how the depth of field (DOF) of a projection can be greatly enhanced. This allows focussed imagery to be shown on complex screens with varying distances to the projectors focal plane, such as projection domes as in planetariums or cylindrical canvases as in IMAX theaters. We demonstrate that adaptive apertures outperform previous methods of projector defocus compensation for objective lenses with static apertures. In addition, our adaptive apertures can perform the type of temporal contrast enhancement employed by common auto-iris projection lenses, and also produce high-quality de-pixelated images. The latter is beneficial for close-view displays with limited resolution, such as rear-projected TV sets.

Several approaches have been proposed to increase the DOF of conventional projectors using image deconvolution with known point-spread functions (PSF). All of these approaches share two limitations: Firstly, they are far from being able to reach real-time performance – not even if the time necessary for measuring the local blur functions is not considered. This prevents them from displaying dynamic content. Secondly, the amount of defocus that can be compensated through deconvolution is clearly limited when the PSF is Gaussian. Ringing artifacts will dominate if the blur becomes too large. In fact, only little defocus can be compensated efficiently with such techniques.

We show that if adaptive coded apertures are applied instead of simple static ones (circular or coded), more image details can be recovered from optical defocus while a high light throughput is maintained. Furthermore, our implementation uses the graphics hardware for computation and thus achieves interactive frame-rates of currently 8-16 fps at XGA resolution.

Our approach computes and displays a dynamic aperture pattern, based on the analysis of the projected image content and on limitations of human visual perception. This analysis allows us to determine and filter out spatial frequencies of the input image that cannot be perceived by a human observer under the given viewing conditions. An optimal aperture can then be computed by maximizing its light transmission while preserving the perceivable frequencies, rather than being restricted to support a constant frequency band. We show that our adaptive apertures produce better results than previous methods with the same or even an increased amount of light transmission.

Adaptive apertures are also useful for planar screens that do not require a large DOF: Defocussing the projector optically to make the pixel structure vanish, and applying deconvolution to recover the image details leads to better image quality. This is known as projector de-pixelation. Our technique enhances projector de-pixelation significantly. For video frames with different brightness, our adaptive aperture can be scaled with respect to the mean image brightness to increase the temporal contrast of a video sequence as conventional auto-iris projection lenses – but with a larger DOF.

In combination with reflective spatial light modulators, adaptive coded apertures can potentially lead to a new generation of auto-iris projector lenses.

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