Coded Lens: Using Coded Aperture for Low-cost and Versatile Imaging

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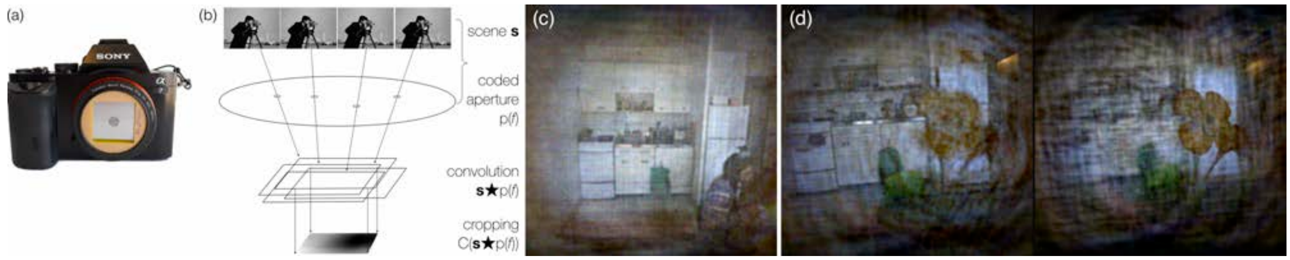

Figure 1: *(a) Prototype, (b) Image formation model, (c) Real scene reconstruction, (d) Adjusting focus*

Abstract

We propose *Coded Lens*, a novel system for lensless photography. The system does not require highly calibrated optics, but instead, utilizes a coded aperture for guiding lights. Compressed sensing (CS) is used to reconstruct scene from the raw image obtained through the coded aperture. Experimenting with synthetic and real scenes, we show the applicability of the technique and also demonstrate additional functionality such as changing focus programmatically. We believe this will lead to a more compact, cheaper and even versatile imaging systems.

1 Introduction

Optical lenses are critical overhead for digital cameras, mainly due to its size and high price. Pinhole cameras bypass this problem. However, they have extremely slow shutter speed making them unsuitable for handheld photography, and provide no control over imaging parameters e.g. focus, aperture size.

A good solution for this is to use multiple pinholes for collecting more lights. From that idea, researchers started exploring the possibility of using coded aperture for X-Ray systems, however, they required additional light-guiding hardware (e.g. collimator) to make perfectly controlled imaging condition [Busboom et al. 1997]. In this paper, we propose a coded aperture imaging technique using CS without need of the lens or light-guiding hardware. It not only provides more compact and affordable optics system, but also the function of digitally focusing image after the picture is taken as in [Veeraraghavan et al. 2007], but without any optical lens.

2 Proposed method

The proposed system is illustrated in Figure 1. It has a layer of coded aperture standing in front of CMOS sensor, which makes the observed image (by the sensor) be convolution of multiple pinhole images projected through each pixel in the aperture. And due to its finite size, the CMOS sensor crops the observed image. We define this observation process using matrix A, which is dependent on the desired focus f,

$$\mathbf{y} = \mathbf{A}(f)\,\mathbf{s} = \mathbf{C}_f\left(\mathbf{s} \star p(f)\right) \tag{1}$$

where $p(f)$ is the aperture's point spread function (PSF) and $\mathbf{C}_f$ is cropping function, both dependent on focus parameter f. Our goal is to reconstruct the scene $\mathbf{s}$ from the observation $\mathbf{y}$ with the aperture pattern and the desired focus f given. However, the convolution and the cropping make the observation incomplete, and therefore, making the reconstruction difficult.

CS theory provides good strategy dealing with such missing observation problem. If the scene $\mathbf{s}$ can be regarded as a sparse signal $\mathbf{x}$ in some basis $\mathbf{\Psi}$, the scene s can be reconstructed from incomplete observation $\mathbf{y}$

$$\min \alpha \cdot \mathrm{TV}(\mathbf{s}) + \beta \cdot |\mathbf{\Psi s}|_{l1}\,,\ s.t.\ \mathbf{A}(f)\,\mathbf{\Psi}^{-1}\mathbf{x} = \mathbf{y} \tag{2}$$

where TV is total variation function (TV) for smoothness constraint, and α, β are weight for TV and L1 term. However, because A is a large matrix, it is impractical to use equation (1) for this optimization. For this, we can rewrite equation (1) as $\mathbf{y} = \mathbf{C}_f(\mathrm{ifft2}(\mathbf{D}(p(f)) \otimes \mathrm{fft2}(\mathbf{s}))$ where, $\mathbf{D}$ is Optical Transfer Function (OTF) [Yin et al. 2010]. This makes the computation reasonably efficient.

3 Experiment

We used Sony Alpha7 camera (24 mega pixels 14bit RGB) with a aperture pattern mask (size of 23.9mm square, and 0.188mm per each pixel). Initial reconstruction was obtained using L-2 minimization with Sparse Equations and Least Squares algorithm, and then the result was optimized through CS framewrok. Results are shown in Figure 1 - (c) shows a successful reconstruction of a indoor scene, and (d) demonstrates computationally adjusting the distance of focal plane by changing matrix A.

References

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