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On Plenoptic Multiplexing and Reconstruction

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Abstract Photography has been striving to capture an ever increasing amount of visual information in a single image. Digital sensors, however, are limited to recording a small subset of the desired information at each pixel. A common approach to overcoming the limitations of sensing hardware is the optical multiplexing of high-dimensional data into a photograph. While this is a well-studied topic for imaging with color filter arrays, we develop a mathematical framework that generalizes multiplexed imaging to all dimensions of the plenoptic function. This framework unifies a wide variety of existing approaches to analyze and reconstruct multiplexed data in either the spatial or the frequency domain. We demonstrate many practical applications of our framework including high-quality light field reconstruction, the first comparative noise analysis of light field attenuation masks, and an analysis of aliasing in multiplexing applications.

Keywords Computational photography · Optical multiplexing · Plenoptic function · Light fields

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1 Introduction

Despite the tremendous advances in camera technology throughout the last decades, the basic principle of operation of modern cameras is still the same as that of Joseph Nicéphore Niépce's camera, which he used to capture the first permanent photograph in 1826. Digital sensors have replaced light sensitive resins and on-board image processing using integrated computing hardware is now common practice, even for consumer-grade digital cameras. However, the acquired visual information has always been what a single human eye can perceive: a two-dimensional trichromatic image. Fueled by advances of digital camera technology and computational processing, image acquisition has begun to transcend limitations of film-based analog photography.

Computational photography has emerged as an interdisciplinary field that is dedicated to the exploration of sophisticated approaches to capturing, analyzing, and processing visual information. Most of the proposed techniques aim at acquiring the dimensions of the plenoptic function (Adelson and Bergen 1991) with combined optical modulation and computational processing (Wetzstein et al. 2011). The plenoptic function provides a ray-based model of light encompassing most properties of interest for image acquisition, including the color spectrum as well as spatial, temporal, and directional light variation.

A most desirable plenoptic camera would capture all plenoptic dimensions in a single image using *plenoptic multiplexing*. This can be achieved with something as simple as a color filter array or, more generally, consider additional plenoptic quantities (Narasimhan and Nayar 2005). In either case, a full-resolution image is computed from an interleaved sensor image by interpolating the captured data. Alternatively, an encoding of the spatio-angular plenoptic dimensions, commonly referred to as light fields (Levoy and