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Exploiting Plenoptic Imaging for Depth Sensing and Visualization Enhancement

Paolo Favaro   Tom E. Bishop   Sara Zanetti

P.Favaro@hw.ac.uk   T.E.Bishop@hw.ac.uk   SZ73@hw.ac.uk

Introduction

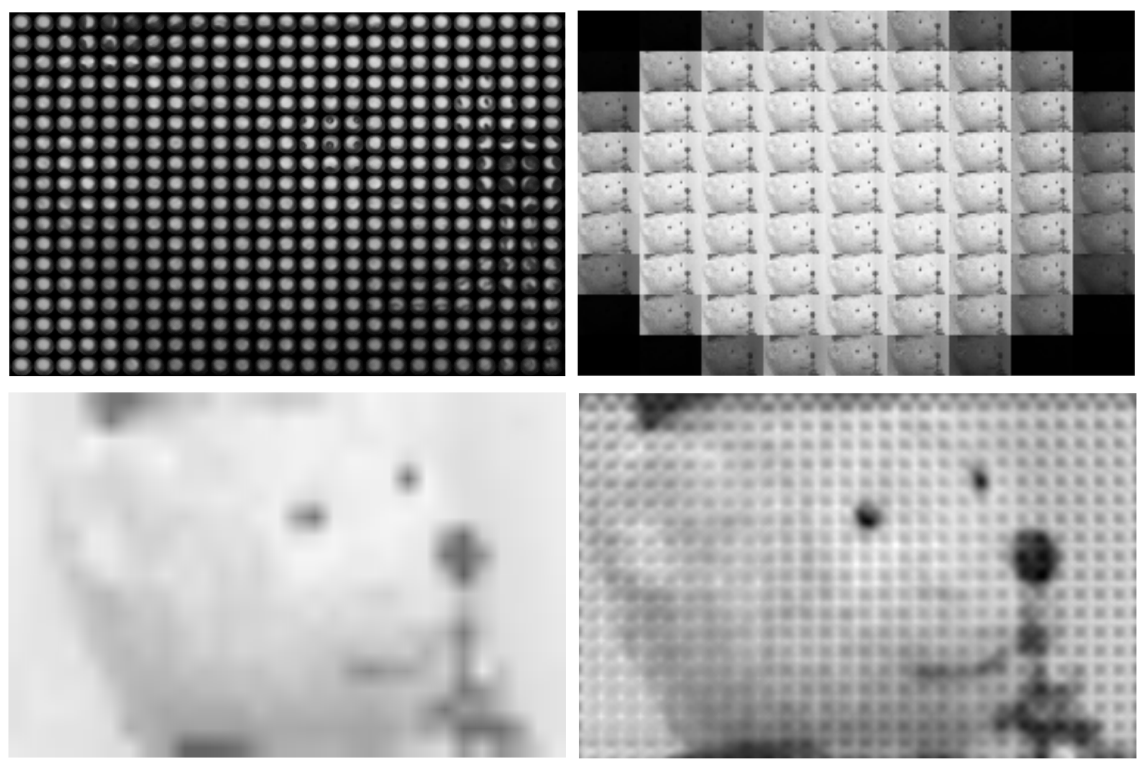
Computational Photography is a new emerging field created by the convergence of computer graphics, computer vision and optics. Unbounded dynamic range, variable focus, resolution, and depth of field, inference of shape, reflectance, and lighting, and new interactive forms of photos that are partly snapshots and partly videos are just some of the new applications found in this field. Among the new system designs in the context of Computational Photography, we consider the plenoptic camera (see Figure to the right), originally introduced by Adelson and Wang [1] and recently applied to digital refocusing by Ng et al. [2]. This camera allows to capture several views of an object in a single snapshot, a sensing modality called plenoptic imaging. One of the main advantages of this modality is that it allows to deal with dynamic scenes and non Lambertian objects.

In the figure to the right we show our plenoptic camera prototype: We use a H2 Hasselblad medium format camera (top image) equipped with a 16MP digital back from Megavision (bottom image). We placed an interface with an array of about 300x300 circular microlenses above the sensor. The interface has an inner frame carrying the microlens array that can freely float in space (can be both translated and rotated in 3D).

We are interested in using our prototype for depth sensing, i.e., for determining the distance between an object and the observer for the purpose of autonomous navigation, gesture detection and recognition, and visualization enhancement, i.e., for restoring or improving the rendering of our measurements in applications such as surveillance and medical imaging.

A First Application: Light Field Superresolution

Current methods for plenoptic imaging yield a low resolution light field as they trade off spatial resolution for angular resolution. We propose overcoming this limitation by exploiting the structure of the light field via superresolution.



For instance, we are given in input the light field shown in the figure to the right (top left image), and we are interested in combining the multiple views of the same object (top right image) so that one view (bottom left image) is superresolved of several times (bottom right image).

We pose superresolution as the task of recovering both the unknown shifts of each single view and the blending of the samples from each low-resolution view. The first step amounts to estimating the depth map of the scene while the second step amounts to solving a deconvolution problem.

Superresolution: A Bayesian Formulation

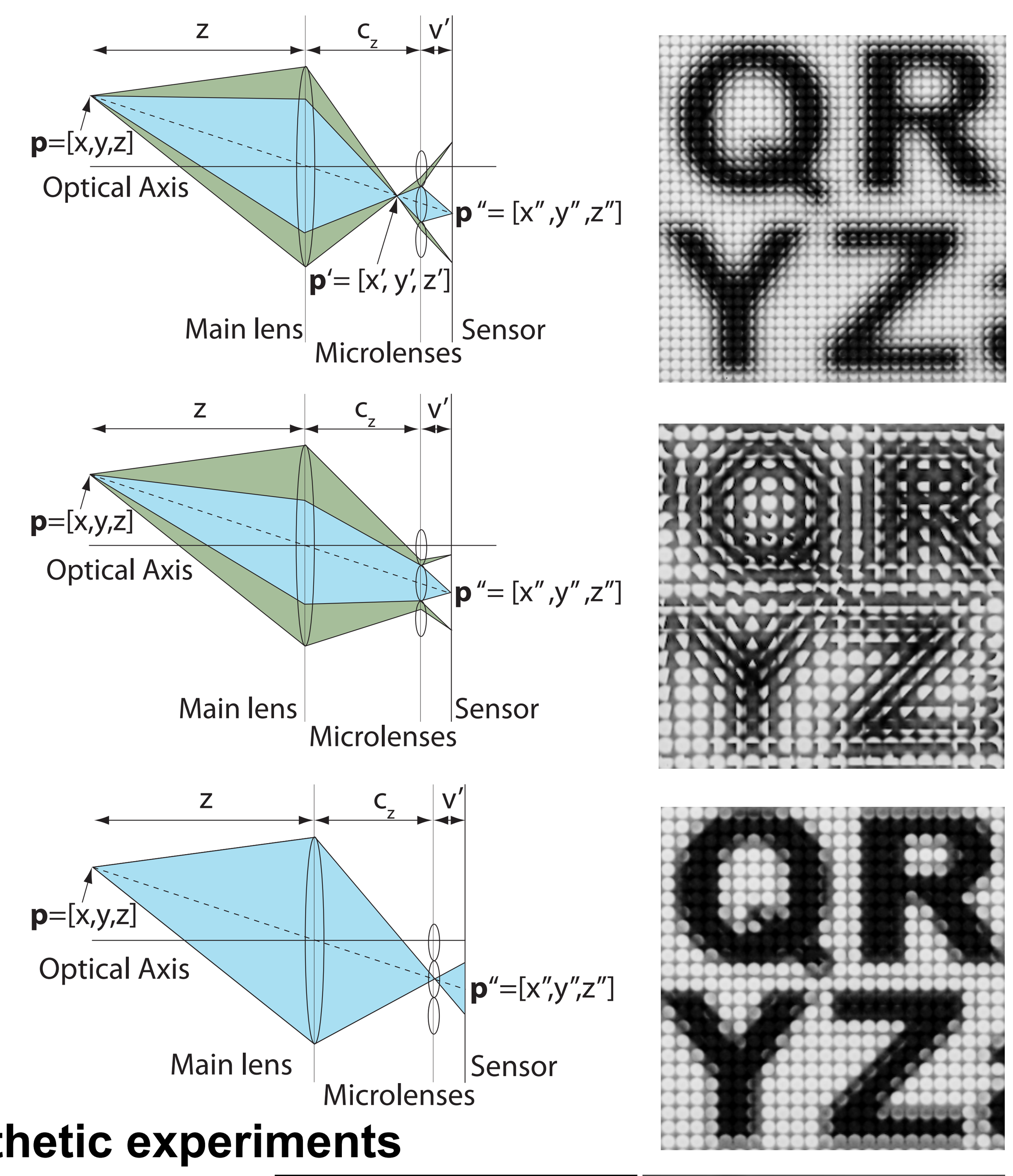


Image formation model

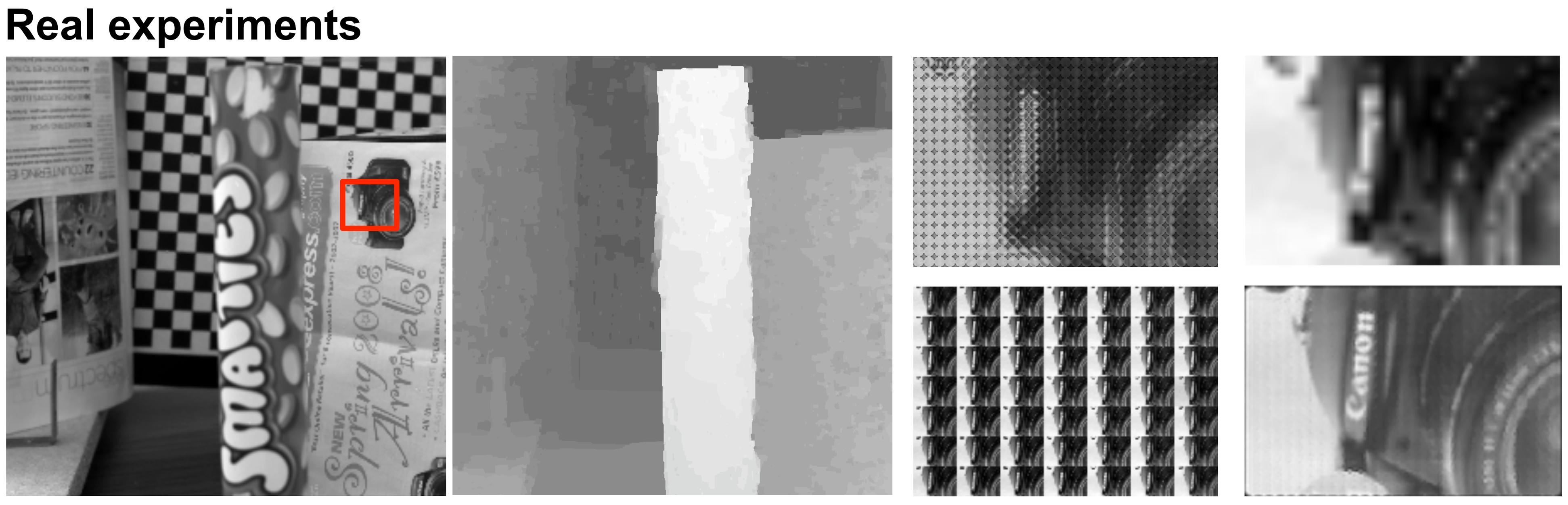
We use a light field camera (similar to Ng's camera [2]). A schematic of a 2D section of such system is shown in the figure to the right. By starting from the left in each diagram, the plenoptic camera consists of a main lens, a microlens array, and a sensor. The light emitted by a point in space **p** is deflected by the main lens and then split into several beams by the microlens array. The size of some microlenses has been exaggerated only for visualization purposes. Top row: Case of multiple repetitions with no flipping (main lens out of focus). Middle row: Case of multiple repetitions with flipping (main lens out of focus). Bottom row: Case with no repetitions (main lens in focus).

Bayes algorithm

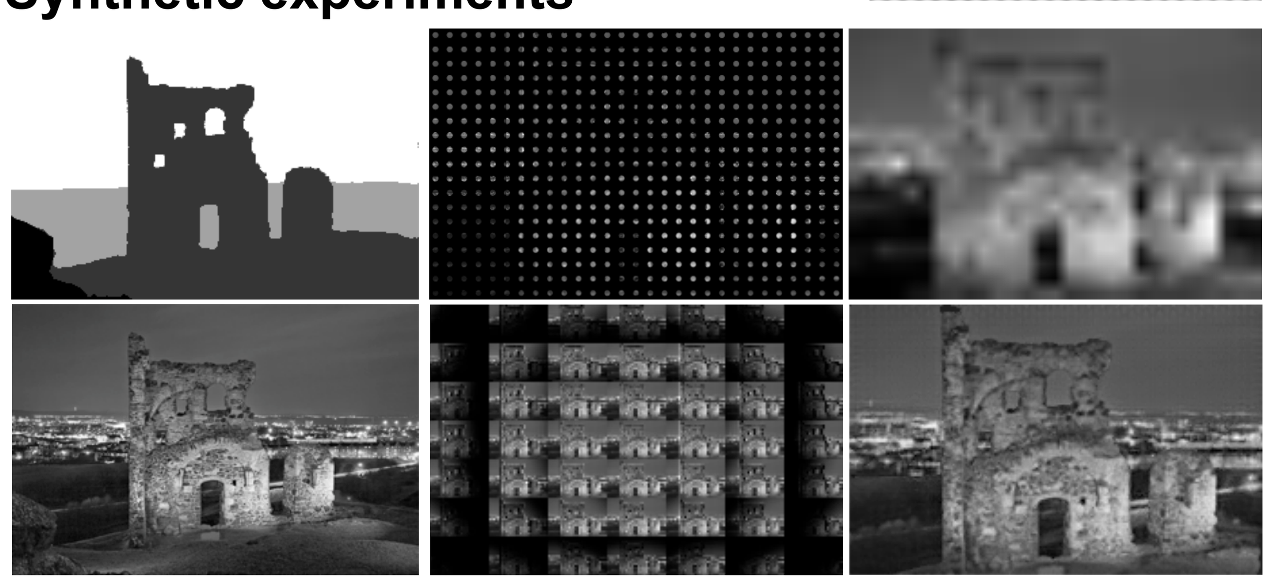
The plenoptic camera model is given by the equation $\mathbf{l} = \mathbf{H}\mathbf{r} + \boldsymbol{\omega}$, where **l** is the captured light field image, **r** is the reflectance, **H** is a sparse matrix representing the point spread function of the plenoptic camera that depends on the depth, and **w** is additive Gaussian noise. We estimate the radiance **r** in a Bayesian framework using the image prior $\mathbf{p}(\mathbf{r}|\mathbf{a}, \boldsymbol{\sigma}_u) = \mathcal{N}(\mathbf{r}|0, \boldsymbol{\Sigma}_r)$ solved via conjugate gradient least squares.

Results

Real experiments



Synthetic experiments



[1] E. H. Adelson and J. Y. Wang. Single lens stereo with a plenoptic camera, *IEEE J. PAMI*, 14(2):99-106, Feb 1992.
[2] R. Ng, M. Levoy, M. Bredif, G. Duval, M. Horowitz, and P. Hanrahan. Light field photography with a hand-held plenoptic camera. Technical report CSTR 2005-02, Stanford University, April 2005.