Evaluation of blur kernel estimation using Camera Simulation

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Introduction

The image processing pipeline refers to the steps involved from the acquisition of a scene to the rendering of an image. The components of the pipeline capture, process and store an image.

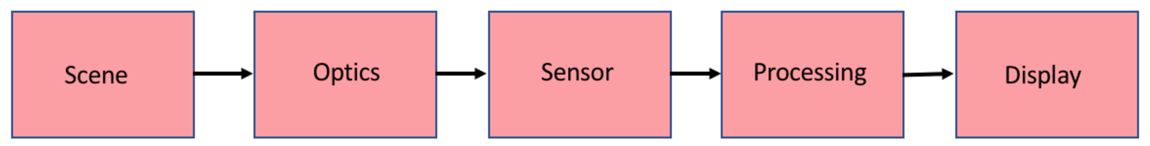


Image Processing Pipeline

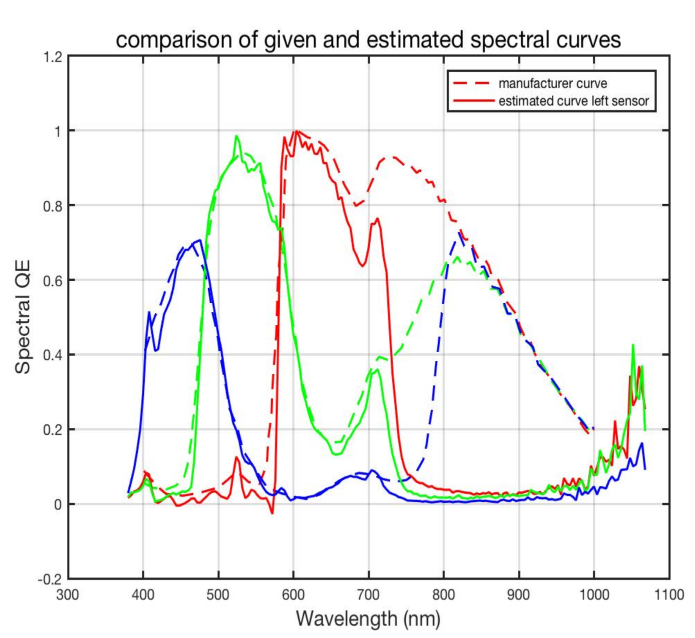
Our objective was to build a simulation of the image processing pipeline for a stereo camera. We envisioned the simulation as a useful tool that can enable cost-efficient and rapid prototyping, guide development of sensor components, and provide predictions of performance in settings that are difficult to measure.

We explore one potential application in this project, and use the simulation to evaluate a state-of-the-art blur kernel estimation method [3].

Previous Work

Estimation of Spectral and Noise Characteristics:

The spectral quantum efficiencies of a sensor is the relative efficiency of detection of light as a function of wavelength. To estimate this we captured images of a set of narrowband lights, and measured the spectral power distributions.



Spectral Quantum Efficiency of stereo camera

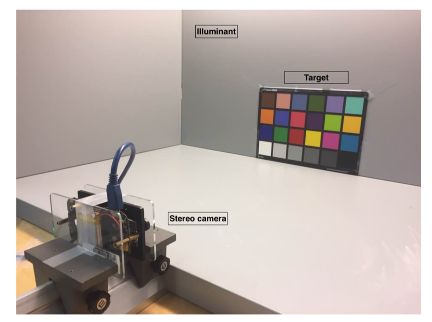
We estimated the noise characteristics of the camera, namely read noise, dark voltage, DSNU and PRNU by capturing dark field and light field images using the camera.

Using the spectral and noise characteristics, we build a simulation of the sensor.

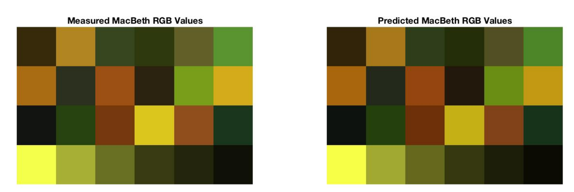
Methods

Validation of sensor simulation

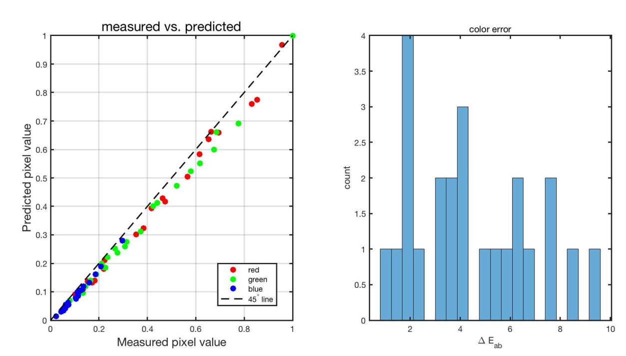
Measured vs. predicted colors of Macbeth Color Checker



Experimental setup



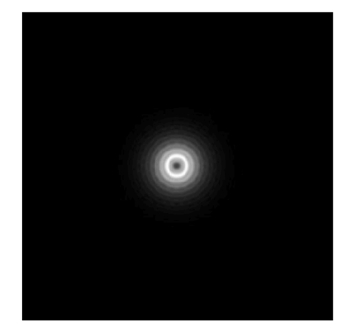
Qualitative comparison



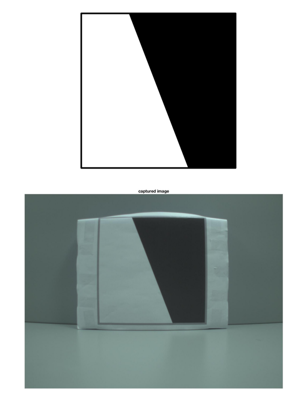
Quantitative comparison

Construction and validation of optics model

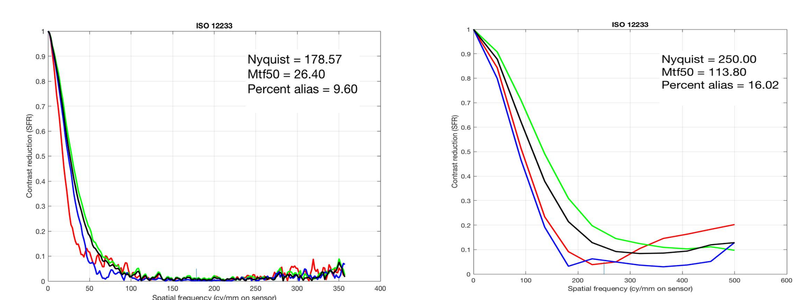
1. Point spread functions exported from Zemax
2. Optics simulation model using ISET raytracing
3. Validation using slanted line target



Ground-truth PSF from the lens file



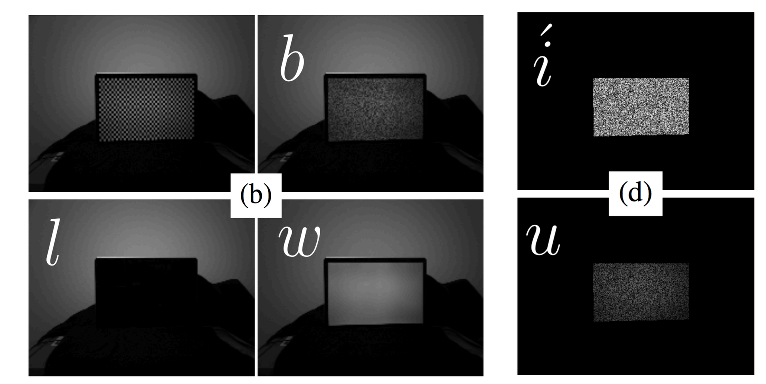
Slanted bar target



Comparison of measured and predicted MTF

PSF Estimation

1. Alignment: Capture four target images, align ideal noise image to be in same space as captured noise image
2. Optimization: Solve for PSF by minimizing objective function



Captured Images

Aligned Images

$$min_k E(k) = \underbrace{\|\hat{u}k - \hat{b}\|^2}_{\text{Data fidelity term}} + \underbrace{\lambda\|k\|^2}_{\text{sparsity prior}} + \underbrace{\mu\|\Delta k\|^2}_{\text{smoothness prior}} + \underbrace{\gamma\||\mathcal{F}(k)| - |\mathcal{F}(k')|\|^2}_{\text{prior on PSF}}, \underbrace{\text{s.t } k > 0}_{\text{PSF constrained to be positive}}$$

Optimization objective

Discussion

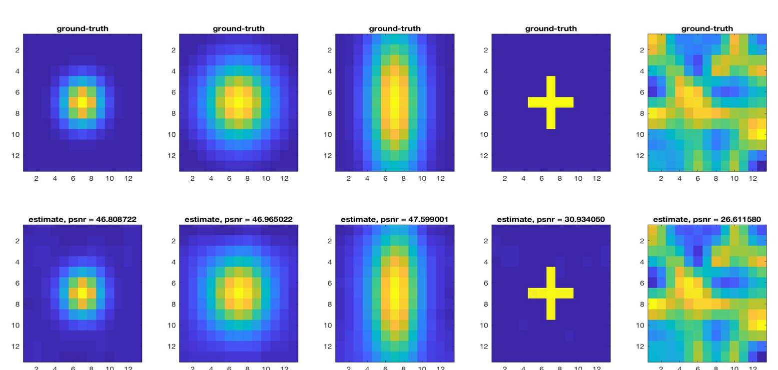
The optics simulation can be improved on. Data on geometric distortion and relative illumination found using the lens model in Zemax can improve the prediction.

Currently the ISET ray tracing method assumes that radial symmetry applies to the distribution of PSFs, and interpolates them accordingly. This may not hold.

The PSF estimation method has sparsity and smoothness priors in the objective function. It may perform poorly with unusual or non-smooth PSFs. This can be explored with the ISET simulation model.

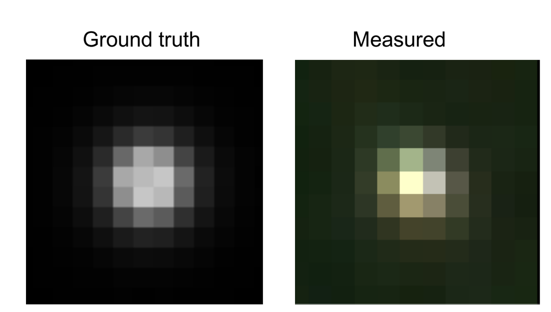
Experimental Results

Validation of Optimization part of PSF estimation

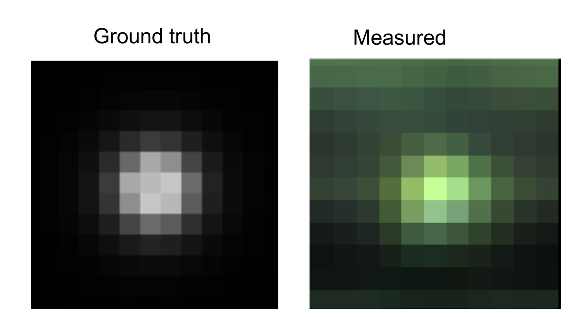


Results of optimization for different gorund truth kernels

Comparison of estimate for camera with ground-truth PSFs

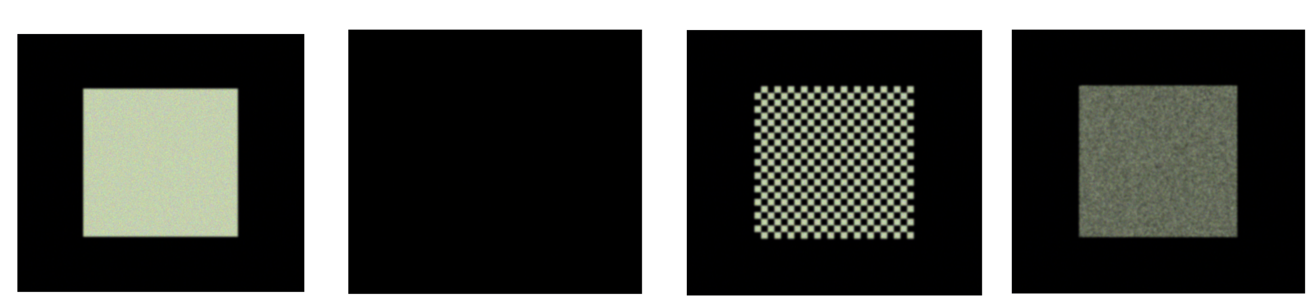


Centre PSF

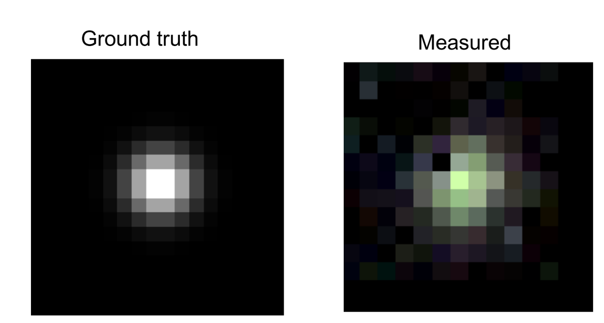


Edge PSF

Evaluation using ISET prediction



Simulation of camera output for target images



References

[1] J. Farrell, P.B. Catrysee, B. Wandell. “Digital camera simulation”. Applied Optics. 51(4)80-90. (2012).
[2] J. Farrell, M. Okincha and M. Parmar. “Sensor calibration and simulation.” Proc. SPIE 6817. 68170R (2008).
[3] Mosleh,A., Green,P., Onzon,E., Begin,I., Langlois,J. ,”Camera Instrinsic Blur Kernel Estimation: A Reliable Framework” IEEE CVPR (2015)
[4] “ZeMax to ISET: Importing Optics Files” http://scarlet.stanford.edu/teach/index.php/TravisAllen747

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