Supplementary Material

Dual Aperture Photography: Image and Depth from a Mobile Camera

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This supplementary material accompanies the paper "Dual Aperture Photography: Image and Depth from a Mobile Camera" at ICCP 2015. It provides more details regarding the image quality analysis of a DA camera (in particular compared to a conventional camera), and the depth estimation performance (compared to prior work).

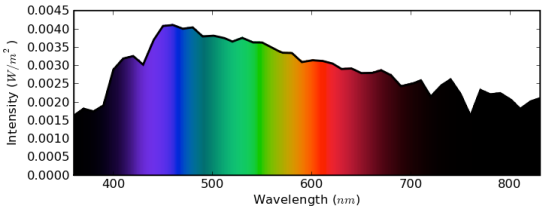
1. Color Quality Comparison

Figure 1 reports a side-by-side comparison between a conventional camera and a DA camera; both cameras use the same type of sensor, although in the DA camera the Bayer pattern has been altered. The standard illuminance D65 (similar to day sunlight) has been chosen to perform this comparison because of its wide spectrum and strong level of near-infrared, as displayed in Figure 1(a).

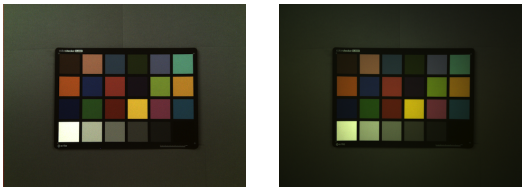
To evaluate the results we use the Imatest tool[1]: for each colored patch in the chart, the tool compares the value of the color in the captured image with its reference. In Figure 1(d) these two values are represented by a disk and a square respectively: the distance between the two values represents the color error. Some statistics are reported at the top right corner of each graphs. Although the original images show a significant difference, after IR removal and color correction the image captured with the DA camera shows colors that are very similar to those obtained from a conventional camera.

2. IR Removal

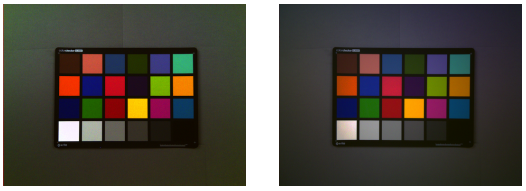
In Figure 2 we illustrate the effect of the IR removal task described in the main paper (Section 4.4). In the DA camera that we have used for this experiment the weights α_i, obtained from equation (8) and then used in equation (7), are the following: $\alpha_R = 0.88$, $\alpha_G = 0.56$, and $\alpha_B = 0.42$.



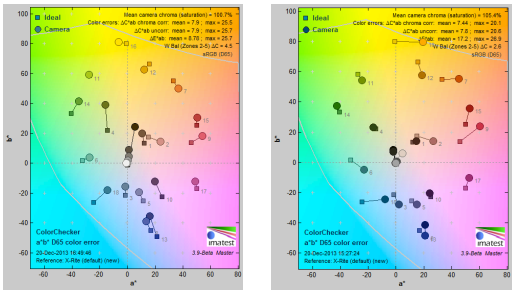
(a) D65 illuminance (similar to day sunlight)



(b) Captured RGB images (unprocessed)



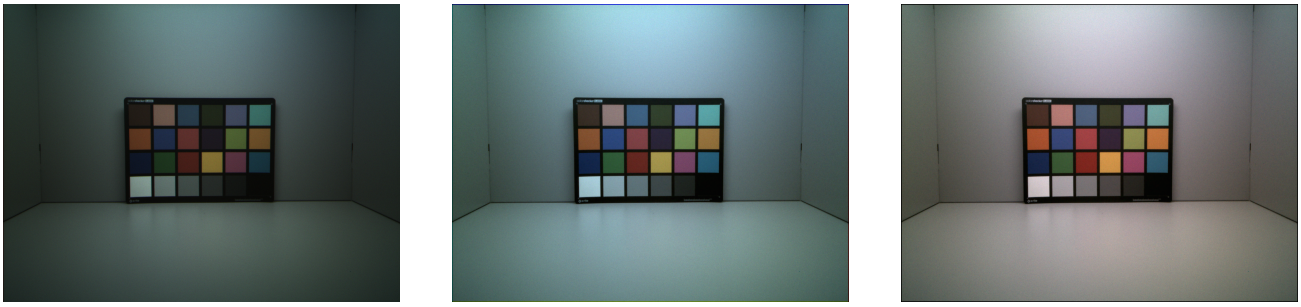
(c) After IR removal and color correction



(d) Color evaluation graphs (from Imatest)

Figure 1. **Color quality comparison.** We test our camera under D65 light (day sunlight) **Left**: conventional camera with a Bayer pattern sensor; **Right**: DA camera with an RGB-IR sensor.

[1]Data processed with Imatest v.3.9β (http://www.imatest.com).



(a) Input RGB image (unprocessed) (b) After IR removal (c) After white balance

Figure 2. **IR removal.** Effect of the IR removal on a color image captured with a DA camera.

3. From Blur Size to Absolute Depth

Since the DA device is based on a conventional camera, they share the same image formation model for the RGB image. Hence the link between the size of the RGB blur $|\boldsymbol{h}_k^{rgb}|$ and the absolute distance from the camera z is given by

$$|\boldsymbol{h}_k^{rgb}| \doteq \frac{A^{rgb}}{\gamma} \left| 1 - \frac{v}{v_0(z)} \right| , \tag{1}$$

with

$$v_0(z) = \frac{F\ z}{z - F} , \tag{2}$$

where A^{rgb} is the lens aperture for the RGB components, F is the focal length of the main lens, γ represents the pixel size, and v indicates the distance lens-sensor, which set the focus distance of the camera.

By rearranging the terms in equation (1) we can extract the absolute depth z of an object by knowing the size of its blur $|\boldsymbol{h}_k^{rgb}|$ and the focus setting of the camera v

$$z = \frac{v\ A^{rgb}\ F}{F\gamma|PSF_k| + vA^{rgb} - FA^{rgb}} \tag{3}$$

4. Depth Estimation performance

As described in Section 6.1 of the main paper, we analyze the performance of the depth estimation method by using a procedure similar to the one described in [20]. We use 2 types of textures, as shown in Figure 3: grayscale random texture and a collection of color patches from real images.

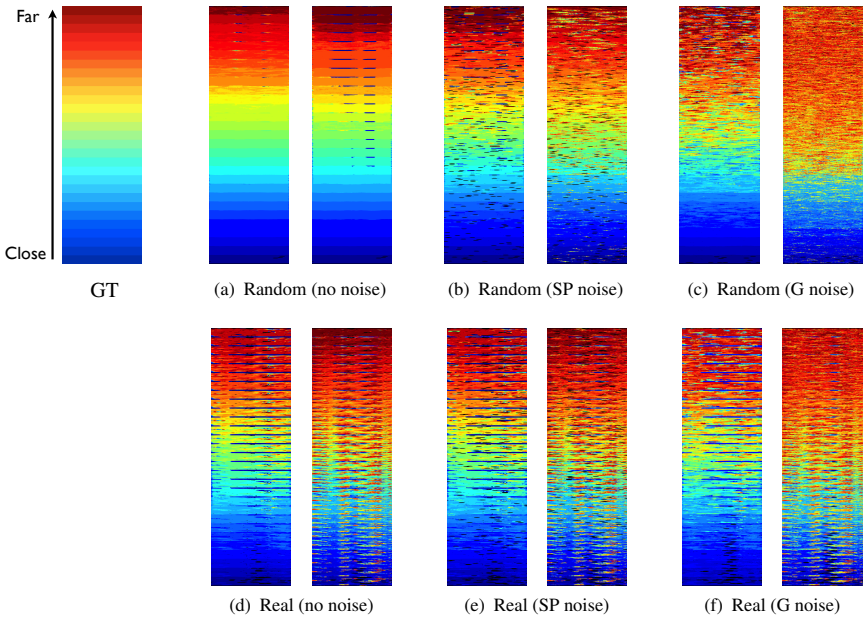
In this work we consider 29 kernels (different sizes of blur) and synthetically blur the selected texture image (from Figure 3) with each of them. Then we stick the blurred images into a single tall image and use it to estimate the size of the blur (which represents the relative depth from the focus plane). The ground-truth (GT) is showed at the top

(a) Random (b) Real

Figure 3. **Textures.** These two different types of texture have been used to evaluate the depth estimation algorithm.

left of Figure 4: blur colors indicates small blurs, therefore area close to the focal plane, while warm colors indicates large blurs (far from the focal plane). Each step of the depth maps in Figure 4 is the same size of the relative texture in Figure 3, but it has been squeezed along the vertical axis in the actual illustration to fit in the paper.

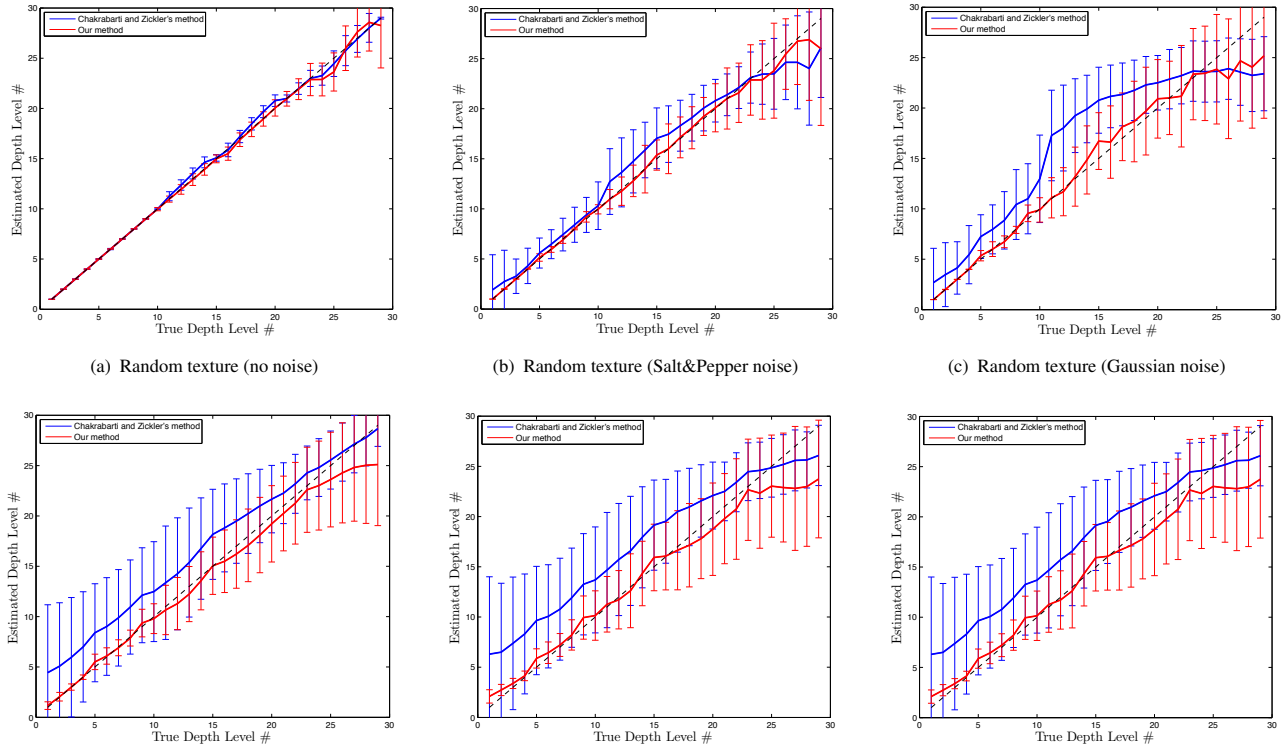
Two different types of noise have been considered in the performance comparison: Salt&Pepper (SP) and Gaussian (G). Compared to [6], our depth estimation method gives more accurate results even when the input data has been altered by some noise.



GT (a) Random (no noise) (b) Random (SP noise) (c) Random (G noise)

(d) Real (no noise) (e) Real (SP noise) (f) Real (G noise)

Figure 4. **Performance comparison (depth map).** Each pair of depth maps display the result from our method (left map) and from the method proposed in [6] (right map). Ground-truth (GT) is shown at the top left: blue colors indicate small size blurs (close to the focus distance) and red colors indicates large blurs (away from the focus distance).



(a) Random texture (no noise) (b) Random texture (Salt&Pepper noise) (c) Random texture (Gaussian noise)

(d) Real texture (no noise) (e) Real texture (Salt&Pepper noise) (f) Real texture (Gaussian noise)

Figure 5. **Performance comparison (graphs).** Each pair of graphs reports the performances for our proposed blur estimation algorithm (red curve) and for the method proposed in [6] (blue curve). Both mean and standard deviation of the estimated blur scale are shown in an error-bar with the algorithms performances (solid line) over the ideal characteristic curve (diagonal dashed line) for 29 blur sizes.