Depth from Focus with Your Mobile Phone
Supplementary Materials

Supasorn Suwajanakorn[1,3], Carlos Hernandez[2] and Steven M. Seitz[1,2]

[1]University of Washington [2]Google Inc.

1. Focal Stack Calibration Experiments

In Figure 1, we plot the initial, calibrated, and ground-truth focal depths as a function of focal stack frame for the "books" ground-truth sequence captured with a Nikon D80 and a 18-135mm lens at 22mm. The initial focal depth of the first and last frames before the calibration are arbitrarily set to 10 and 32 inches, and focal depths in between are linearly interpolated. Because our calibrated focal depths are recovered up to an affine ambiguity in the inverse depth, we solve for 2-dof affine parameters α and β in:

$$\frac{1}{\hat{f}} = \frac{\alpha}{f} + \beta, \tag{1}$$

such that they fit the focal depth of the first frame (the box of playing cards) f_1 to the ground-truth $\hat{f}_1 = 12$ inches and the focal depth of the last frame (background) f_{14} to $\hat{f}_{14} = 51$ inches. Then we plot in red for $i = 1 \dots 14$:

$$\hat{f}_i = \frac{1}{\frac{\alpha}{f_i} + \beta}. \tag{2}$$

To plot the ground-truth focal depths, we assume that the focus is operated by adjusting the sensor-to-lens distance and the camera follows the thin-lens model:

$$\frac{1}{F} = \frac{1}{f_i} + \frac{1}{d_i}, \tag{3}$$

where f_i is the focal depth, d_i is the sensor-to-lens distance, and F is the focal length. In our capture, we rotated the focus ring of the DSLR's lens by a fixed angle and we assume that this changes the sensor-to-lens distance linearly. We can then use the ground-truth depths for the four objects, i.e. the box of playing cards (12), the bicycling book (18.5), the cook book (28), and the background (51), and their associated in-focus frame indices (0, 6, 9, 13) to solve for the focal length F, the sensor-to-lens distance of the first frame d_1,

[3]This research was done while the first author was an intern at Google.

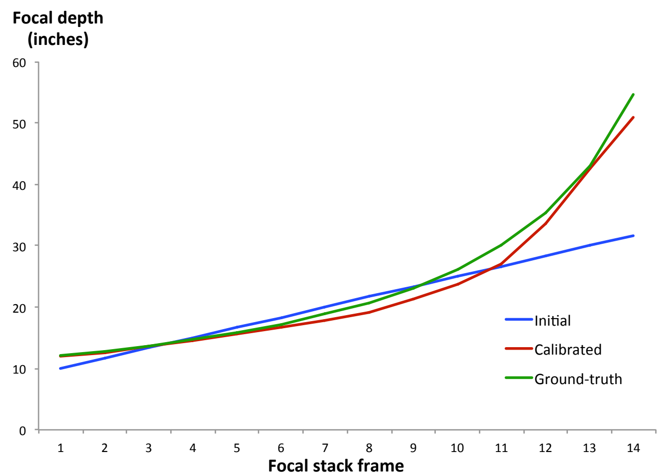

Figure 1. The calibrated focal depths for the "books" ground-truth sequence.

and the sensor-to-lens incremental step k by solving the following over-constrained problem in the least-squares sense:

$$\frac{1}{F} = \frac{1}{12} + \frac{1}{d_1}, \tag{4}$$

$$\frac{1}{F} = \frac{1}{18.5} + \frac{1}{d_1 + 6k}, \tag{5}$$

$$\frac{1}{F} = \frac{1}{28} + \frac{1}{d_1 + 9k}, \tag{6}$$

$$\frac{1}{F} = \frac{1}{51} + \frac{1}{d_1 + 13k}. \tag{7}$$

Then we plot the ground-truth focal depths for $i = 1 \dots 14$ in green as:

$$\tilde{f}_i = \frac{1}{\frac{1}{F} - \frac{1}{d_1 + (i-1)k}}. \tag{8}$$

The plot shows that we are able to recover the non-linear relationship between the frame index and focal depth that fits the ground-truth curve even when the relationship is initialized as linear. In Figure 2, we plot our calibrated sensor-

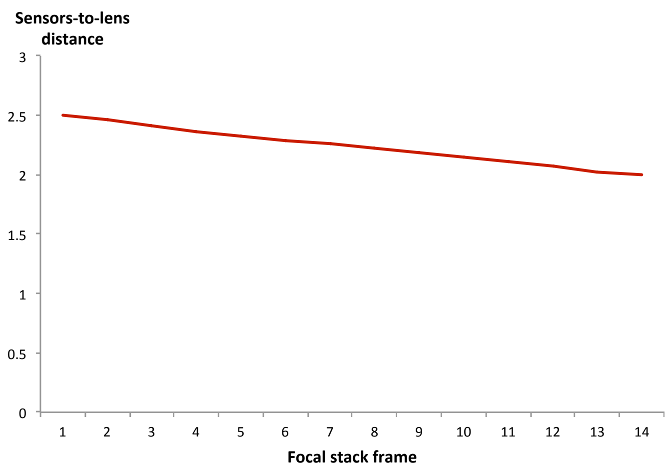

Figure 2. The calibrated sensor-to-lens distances for the "books" ground-truth sequence.

to-lens distances using our calibrated focal length F according to:

$$d_i = \frac{1}{\frac{1}{F} - \frac{1}{f_1}}. \tag{9}$$

The plot shows a linear relationship between the sensor-to-lens distance and focal stack frame agreeing with our assumption that the sensor-to-lens distance changes linearly with a fixed-step rotation of the lens' focus ring.

In Figure 3, we show the initial and calibrated focal depths for each frame in the focal stack for the "balls" sequence, which was taken with a Samsung Galaxy S3 mobile phone. Unlike the DSLR sequence, this sequence was automatically captured during the phone's auto-focus mechanism, which does not guarantee that the sensor-to-lens distance increases linearly. We similarly solve for the 2-dof affine parameters such that the first and last focal depths equal the initial focal depths, and plot the adjusted focal depths. If the sensor-to-lens changes linearly, we would expect the curve to be strictly increasing and similar to the ground-truth curve in Figure 1. However, we discovered from the plot that curve levels off at around frame 23-25 which shows the auto-focusing slowly coming to a stop. This recovered relationship between the frame index and focal depths is necessary for applications such as refocusing, which we show in our supplementary video.

2. Video Demonstration

In our supplementary video we show results for our alignment algorithm, a comparison between our alignment algorithm and affine alignment, a comparison for our Bokeh-aware alignment, and a refocusing application where we synthetically change the aperture.

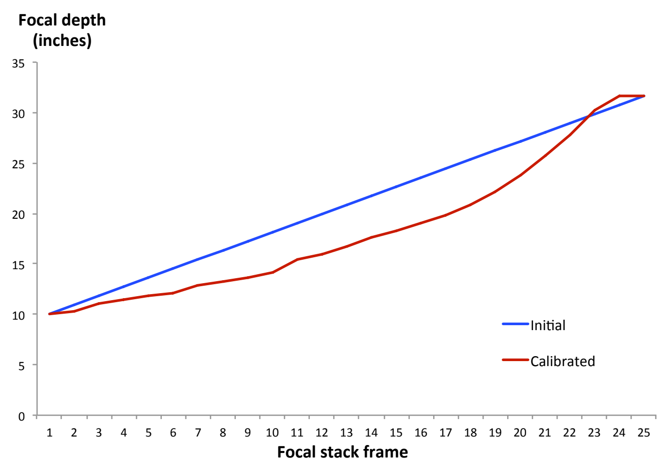

Figure 3. The calibrated focal depths for the mobile "balls" sequence.