Event fields: Capturing light fields at high speed, resolution, and dynamic range

Supplementary Material

1. Calibration details for galvanometer setup

The galvanometer scans on a Lissajous curve, and we need to register the exact location of the galvanometer corresponding to each event time stamp to know the light field view we are measuring. One way to achieve this is to synchronize the event clock with the signal sent to the Galvanometer. However, this complicates the hardware design and generates additional events for the synchronization clock, decreasing the overall useful bandwidth. Instead, we took an algorithmic approach to achieve this synchronization using the captured event field data itself.

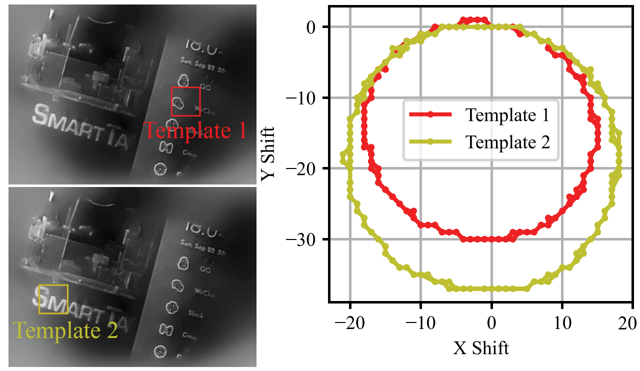
The key idea for the algorithmic approach is the observation that any patch in the reconstructed sequence of images will best correlate with other images in the sequence along the scanned Lissajous curve path. For example, we use circular Lissajous curves for scanning in Supp. Fig. 1. For two patches, we show the shifts for best-correlated patches for all subsequent reconstructed frames and notice that the shifts lie on a circle. The size of the circle (or, in general, the size of the Lissajous curve) depends on the depth of the patch. Therefore, by computing the view of the first frame (i.e., its location on the scanning curve), we calibrate the views for the entire light field sequence. This calibration can be accomplished from just one patch and by correlating with as few as three images for circular Lissajous curves, though we used 40 images for robustness.

In Supp. Fig. 2, we use this procedure to calibrate the light field views and use the equations in Sec. 3.1 to refocus the reconstructed light field at different depths. We show two images corresponding to the back refocus and front refocus of the light field data for two static scenes along the rows. In the main manuscript, we also showed refocusing results for dynamic scenes. (see Fig. 10 and Fig. 11)

2. Depth Calibration Details

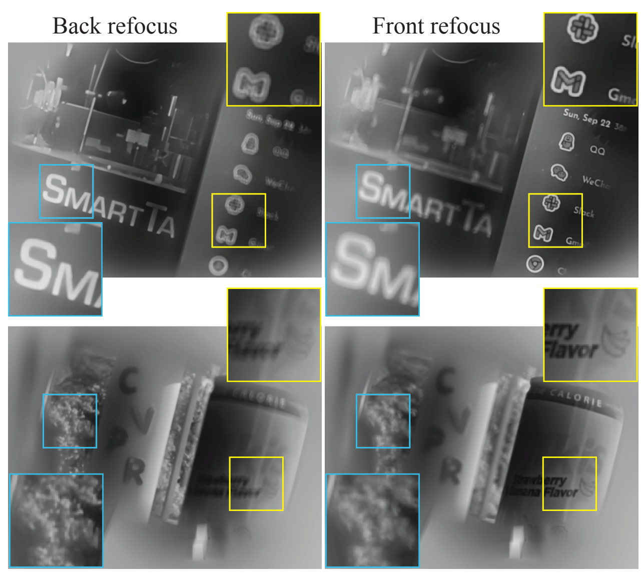
Event fields capture multi-view images and hence capture true-depth information about the scene. As mentioned in Sec. 6.5, we use depth from focus to capture the depth of each pixel in the scene. The depth from focus gives us disparity (i.e., the size of the Lissajous curve) for each pixel, and as mentioned in the previous section, the size of the Lissajous curve is proportional to the patch depth. We compute the proportionality constant by calibrating the system.

We placed a single bright point light source (LED) at a known depth from the galvanometer and computed the size of the Lissaujous curve. We repeated this experiment for different depth locations of the light source and plotted them as shown in Supp. Fig. 3. The slope of this line gives us the proportionality constant, and the y-intercept (depth = 0) gives us the bias which is the distance between the camera and the galvo location in pixels.

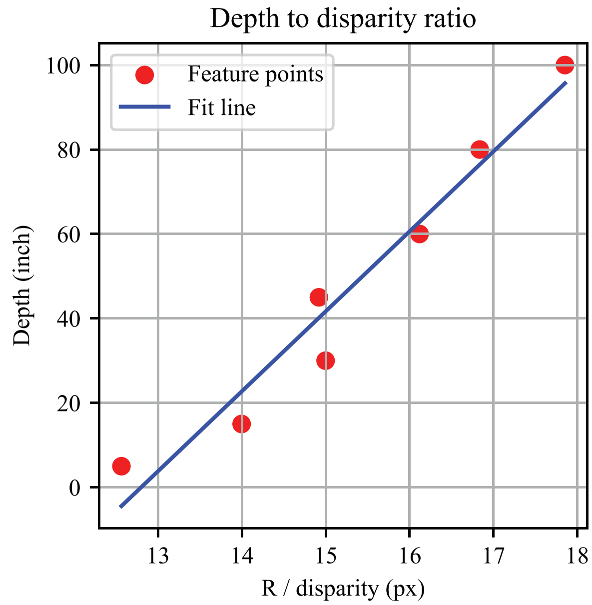


(a) choosen template (b) shift coordinate

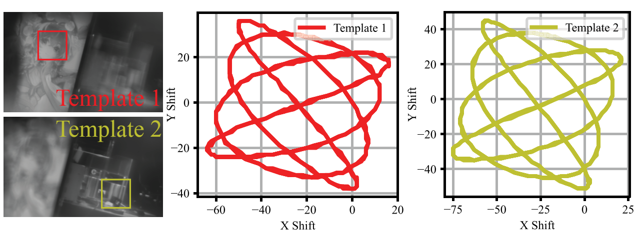
Supp. Figure 1. **Result of template matching.** (a) Two templates are selected from the reconstructed light field image—one in the foreground and one in the background. A template matching algorithm is applied to each template across all light field images to determine the shift amounts in (x,y). (b) The calculated shift amounts are plotted, forming a circular pattern consistent with the scanning curve, validating our concept.



Supp. Figure 2. **Static scene refocusing.** Two distinct static scenes are captured using our galvanometer design at a scan speed of 1 Hz. E2VID is used to reconstruct 100 light field frames. For each scene, we present the reconstructed refocusing result on two selected regions.



Supp. Figure 3. **Depth calibration.** We calibrate 7 depth points using an LED light placed at distances ranging from 15 inches to 100 inches. The depth (in inches) is linearly fitted to the disparity (in pixels) within this range, serving as our calibrated ratio. For new scenes, we detect disparity using a depth-from-focus algorithm and convert it into real-world depth using this calibrated relationship.



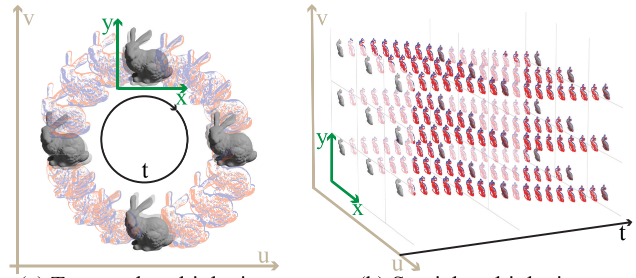
Supp. Figure 4. Scan and refocus with non-circular Lissajous curves.

3. Other Lissajous Curves

The galvanometer supports any Lissajous curves (Supp. Fig. 4), not only circular scan. We can also use a look-up table for arbitrary scanning like Fujii *et al.* [8], but it will slow down the scanning similar to theirs. Calibration details are presented in the supplementary material. Galvos are repeatable, accurate ($\approx 15\mu$rad), and easy to calibrate.

4. Illustration

Since everything is 5D and involves derivatives, we illustrated the event field coordinate in the supplementary video. Following the reviewers' advice, we made Supp. Fig. 5 for detailing the event field coordinate frame in both temporal multiplexing and spatial multiplexing.



(a) Temporal multiplexing (b) Spatial multiplexing

Supp. Figure 5. Temporal multiplexing captures angular derivatives where as spatial multiplexing embeds angular information in spatial domain. (Bunny is falling down.)

5. Codes and Videos

Along with this supplementary PDF, we provide additional materials to support and reproduce the results presented in the paper, including a short video summarizing the paper's contributions, as well as the code and datasets used to generate the results:

- **Images and Videos**: All images and videos from the main paper and supplementary materials are included separately in the "./results/" folder.
- **Refocusing Algorithms and Raw Data**: The code for the refocusing algorithms, based on our kaleidoscope and galvanometer designs, is available on GitHub [43]. Additionally, we provide a short version of the raw data corresponding to the galvanometer design showcased in Fig. 10, as well as the kaleidoscope design highlighted in the slow-motion refocus example in Fig. 1. We will make all these public in the non-anonymous version of the manuscript.