Limits of Resolution. 5. Sensor Shift

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Summary

The high definition shooting mode of the Olympus OM-D E-M5 Mark II is investigated by simulation of line-pair images. The half-photosite shift that is employed to produce 64MP images from a 16MP sensor can, in principle, double the linear resolution that is otherwise achieved by the camera without sensor shifting. However, image pixels obtained at the shifted sensor position are not independent of pixels obtained at the unshifted position: the two sets of pixels overlap completely, with a half-photosite offset. The result is that micro contrast is reduced in comparison with a true doubling of the linear photosite resolution. Given the 3.73 μm photosite pitch of the E-M5 II sensor, the resolution benefits of sensor shifting decrease rapidly at apertures smaller than about f/5.6 because any potential gain in resolution is overwhelmed by diffraction blur (coupled with non-independence of shifted and un-shifted image pixels).

Key words: Olympus OM-D E-M5 Mark II, sensor shift, resolution limits, sampling frequency, diffraction, photosite size, perfect lens, line-pairs, simulation, Airy disk, diffraction-limited resolution, sensor-limited resolution

1. Introduction

The Olympus OM-D E-M5 Mark II, announced in early 2015, has a special high-definition mode in which the sensor is shifted between exposures in an eight-frame sequence that is divided into two sets of four exposures. Sensor shifting has a two-fold purpose. First, within each set of four captures, the sensor is shifted in steps of one photosite. The result is that full RGB color information is obtained for every *image* pixel. In effect, the image is de-mosaicked mechanically rather than computationally. Second, the two sets of four exposures are offset by a one-half photosite shift. This doubles the linear sampling frequency achieved by the sensor. The image pixels corresponding the half photosite shift are inserted between the pixels obtained for the unshifted image.

Both types of sensor shift should increase image sharpness. Mechanical de-mosaicking makes it unnecessary to estimate the missing color components for each image pixel. Conventional de-mosaicking by interpolation is generally thought to reduce linear resolution by a factor of 1.2 – 1.5x. Doubling the linear sampling frequency by means of a half-photosite shift can improve image sharpness in two ways — it potentially doubles the achievable linear resolution of the imaging system; and it increases edge accutance, or microcontrast. This second type of sensor shifting — to increase sampling frequency — is the subject of this paper.

2. Methods

The simulations described here are a straightforward extension of my previous work on the effects of diffraction and photosite size on resolution.[1] For the sake of brevity, I will mention only the most salient points here. A *lens image* of black and white line-pairs is first simulated with diffraction blur. The image is then "sampled" by superimposing a grid of simulated photosites. The sampling process produces the *sensor image.* Any effects of a Bayer color filter array are ignored, and a *perfect lens is assumed.* In other words, resolution is never limited by the lens itself.

I simulated the approximate photosite pitch of the OM-D E-M5 II sensor, 3.73 µm. The simulation output is the contrast-ratio of a sensor-image line-pair pattern as a function of aperture and line-pair frequency. Images were simulated with and without sensor shift. For comparison, I also simulated a sensor with 1.87 µm photosites. That is, the case where doubling of the sampling rate is achieved by doubling the linear density of photosites rather than by sensor shifting. As in my previous papers, the diameter of the diffraction blur circle is taken to be 70% of the diameter of the Airy disk.

3. Results

With 3.73 µm photosite pitch, the Nyquist rate resolution of the unshifted E-M5 II sensor is approximately 134 lp/mm. That is the maximum resolution achievable by the sensor when not limited by lens performance or diffraction. The Nyquist rate resolution of a hypothetical sensor with twice the linear photosite density (1.87 µm pitch) is 268 lp/mm. Provided that the aperture is about f/5.6 or larger, the shifted E-M5 II sensor is capable of achieving comparable resolution, although with much lower contrast (Fig. 1, top and middle panels). At f/8, neither the sensor with 2x phtotosite density nor the shifted sensor can resolve anywhere near 268 lp/mm. Diffraction blur at f/8 effectively smooths away any line-pair pattern for frequencies greater than about 160 lp/mm.[2]

The reason that the sensor shift mode cannot reproduce the contrast ratio of the hypothetical sensor with 1.87 µm photosite pitch is simple. With sensor shift, the image pixels derived from the shift overlap completely with the two unshifted pixels on either side. The "cost" of non-independence is considerably lower micro contrast; which means lower sharpness, or accutance. In short, sensor shifting can give greater resolution than not shifting, but it's not as good for sharpness as doubling the photosite density. No surprise there!

Within the resolution region in which the shifted and unshifted sensor can both operate (< 134 lp/mm), shifting results in modestly higher micro contrast, the effect is not large although it is enhanced at larger apertures (compare the top and bottom panels of Fig. 1). Again, given non-

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[1] Service, Phil. 2014. Limits of Resolution. 1. Sampling Frequency; Limits of Resolution. 2. Diffraction; Limits of Resolution. 3. Diffraction and Photosite Size.

[2] It has been reported that the E-M5 II high definition mode is not available at apertures smaller than f/8. As far as I know, Olympus has not given a reason. The obvious possibility is that resolution gains would be negligible. On the other hand, it would seem that images could still benefit from sensor shifting for mechanical de-mosaicking, regardless of aperture.

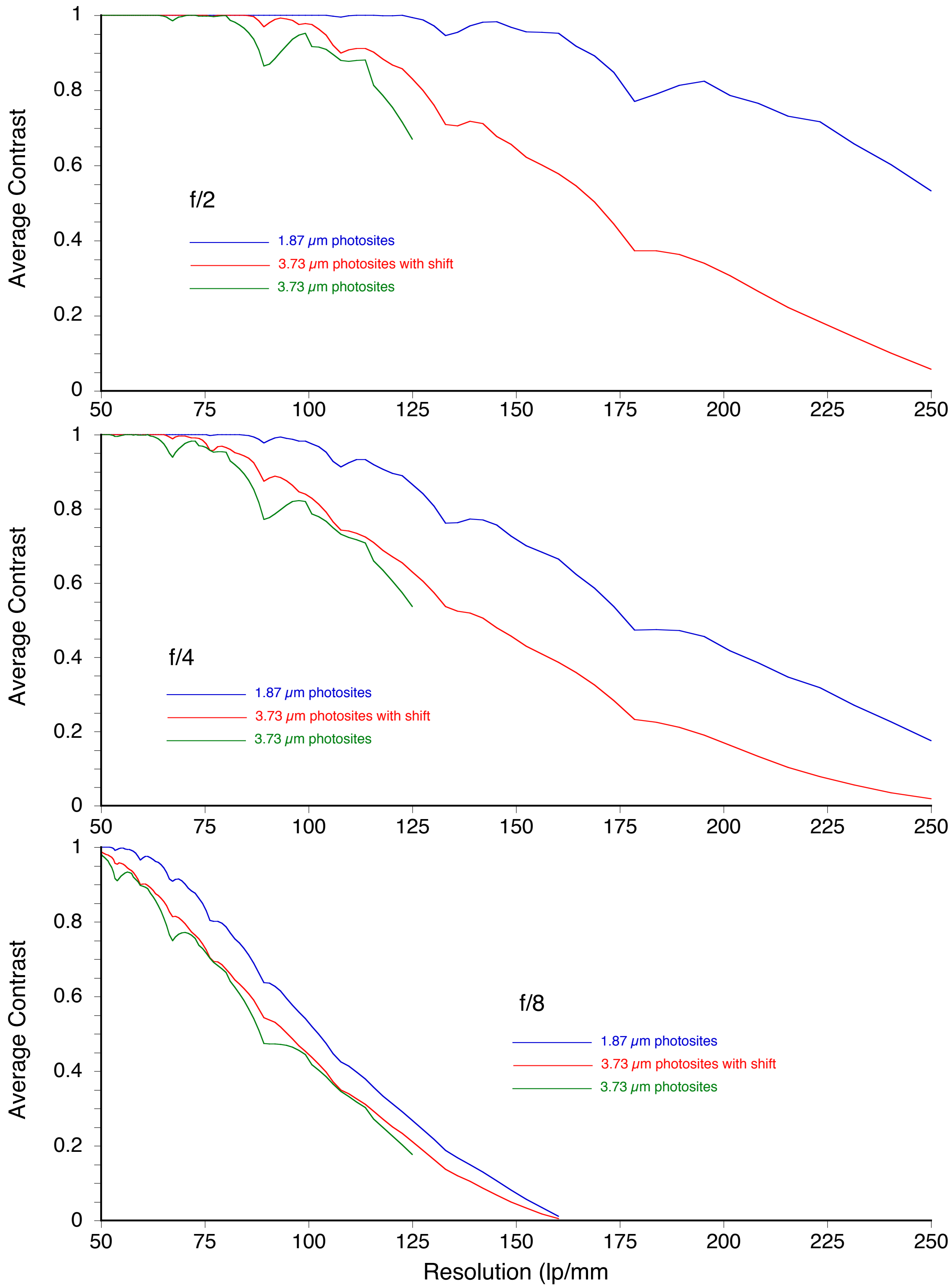

Fig. 1. Theoretical resolution – contrast curves for the Olympus OM-D E-M5 II sensor, with and without sensor shift. A hypothetical sensor with twice the linear photosite density is included for comparison with the shifted sensor. Top panel: f/2; middle f/4; bottom f/8. Note that the origin of the horizontal axis is 50 lp/mm.

independence, these results are not surprising. The hypothetical 2x sensor produces much higher micro contrast even for resolutions < 134 lp/mm.

All of the curves in Fig. 1 show abrupt and reversible changes in slope. These "discontinuities" almost certainly arise from *interactions* between line-pair width and photosite pitch — some line-pair widths do not "play nicely" with the sampling regime imposed by fixed photosite spacings (in this case 3.73 and 1.87 µm).

4. Discussion

These simulations indicate that half-photosite sensor shifting can, in principle, double linear resolution (lp/mm). To achieve such gains, it is necessary to control diffraction by using relatively large apertures. Also, the analysis assumes that resolution is not lens-limited. That is, the lens must actually be able to deliver the doubled resolution to the sensor.

Half-photosite sensor shifting produces modest gains in micro contrast compared to unshifted images with similar resolution. In other words, doubling the sampling frequency improves images only slightly, if at all, when spatial detail frequency is in the realm that can be captured by the unshifted sensor. The modest gains in micro contrast are a result of non-independence of shifted and unshifted image pixels.

Fig. 1 should make it very clear that diffraction blur can be an absolute killer of image detail and sharpness. The penalty is more apparent when the sampling frequency imposed by the sensor is high. In this case, we have simulated sensors with photosite pitches of 3.73 and 1.87 µm. In a previous paper,[3] I showed that when the diffraction blur circle diameter is greater than about 115% of the width of image line-pairs, line-pair contrast falls essentially to zero. The diffraction blur diameter at f/8 is about 7.5 µm. That is 115% of 6.5 µm, which corresponds to 154 lp/mm, which is much less than the theoretical resolution limit of 268 lp/mm for a shifted E-M5 II sensor.

3 Service, Phil. 2014. Limits of Resolution. 2. Diffraction.