On using digital cameras to measure the resolution of Exakta-mount lenses.

Ove Davidsen (a) and Michael Higgins (b)

(a) Åmundsleitet 43 N-5115 ULSET, Norway, ovarda@epost.no

(b) 604 S. Washington Sq. #2814, Philadelphia, PA 19106, USA, mhiggins2814@Netzero.com

Introduction

In our 2007 report, *"On measuring lens resolution with Exakta cameras"*, it was suggested that reduced lens resolution in film cameras could be due to film curling and other sources of film-plain error. The suggestion was that the flatness of digital sensors could provide an improvement in lens resolution tests. After this report was circulated, word was received from Ove Davidsen (OD) that he had already made considerable advances in measuring Exakta lens resolution with an Olympus E-400 digital camera fitted first with an adapter for M42 lenses, and later when it became available also with the 4/3 Exakta adapter. In addition, he described the inroads he had made into understanding the technical problems needed to use digital cameras for this purpose. So we decided that this approach should be investigated further. In this partnership, I Michael Higgins (MLH) used an Olympus digital E-510 camera fitted with a kine Exakta lens adapter, whereas Ove continued to use his E-400 camera with both types of mounts. My adapter came from eBay, as did both of Ove's, but I suggest that if you want a cheaper adapter that you could contact *SRB-GRITURN LTD, Unit 21D, Icknield Way Farm, Tring Road, Dunstable, Beds LU6 2JX ,Tel: 01582 661878*. In the past, I have used this manufacturer to make a Minolta AF adapter with good results.

What we have done then, is to work independently as far as the choice of camera gear, software and working habits are concerned. We have, however, tried to adhere to a common understanding of the principles involved, trying to identify crucial factors necessary to succeed. What we have found we now circulate to the cognoscenti, in the hope that it may tempt more people to take interest in such analyses, as they are now within reach even of those of us who must work on a small budget. The only thing needed is a digital SLR, an adaptor ring, a PC, and some understanding of the general principles. This said, we take as our point of departure that people reading this paper are also familiar with *The Exacta Lens resolution program,* and the work being done previously by the community. If not, you would be well advised to read Mike's paper on this, available on the web at http://.exaktaphile.com/

tests/instruct.pdf before proceeding. So here we go.

Ove's work showed the importance of calculating the maximum number of line pairs per mm that the camera's sensor could measure. The equation for this purpose is shown below. For the clarification of the mathematics involved we would like to give credit to Pete Andrews, who's informative paper on such matters was essential (http://www.photoscientia.co.uk/Grain.htm). The equation gives results in terms of Nyquist-frequency; however, since the Nyquist-frequency relates mathematically to the lp/mm which we have used in our MTF resolution studies we will use this designation in most cases. The following text in *italics* can be skipped if you are turned off by mathematics.

Calculating the maximum number of lp/mm which a digital sensor can resolve

To do this, one needs to know the horizontal length of the sensor in mm and the number pixels found over this same distance. These numbers usually appear in the camera's instruction booklet or given on the manufacture's web site. They are then introduced into a form of the Nyquist-frequency equation shown below.

*Nyquist-Frequency = 1/((horizontal length of the sensor in mm/number of pixels per mm along a horizontal line crossing the sensor)*2)*

Both the Olympus E-400 and the E-510 sensors measures 17.3 X 13 mm, with a sensor pixel count of 3648 x 2736. Substituting the relevant data for the cameras we see that the maximum resolution of their sensors is:

*105.5 lp/mm=1/((17.3mm/3648)*2)*

and the corresponding approximate sensor resolution:

*5356 dpi = 25.4 * 3648/17.3*

*The Nyquist equation infers that in order that a line pair begin to be characterized it must have at least two pixels to report on its image characteristics. This requirement of two pixels per line pair is shown in denominator of the equation by the factor *2. This factor of two reduces the total number of pixels on the sensor in half insuring that the detail in the image with the Nyquist-frequency or less must have its two pixels.*

How does a Nyquist-frequency of 105 stack up against other digital cameras? The Olympus sensors we use have a storage capacity of 10.2 MegaPixels. So how does the Nyquist frequency of these Olympus sensors compare with other cameras, which have much higher capacities? For example, The Cannon EOS 1Ds Mark III has a giant storage capacity of 21

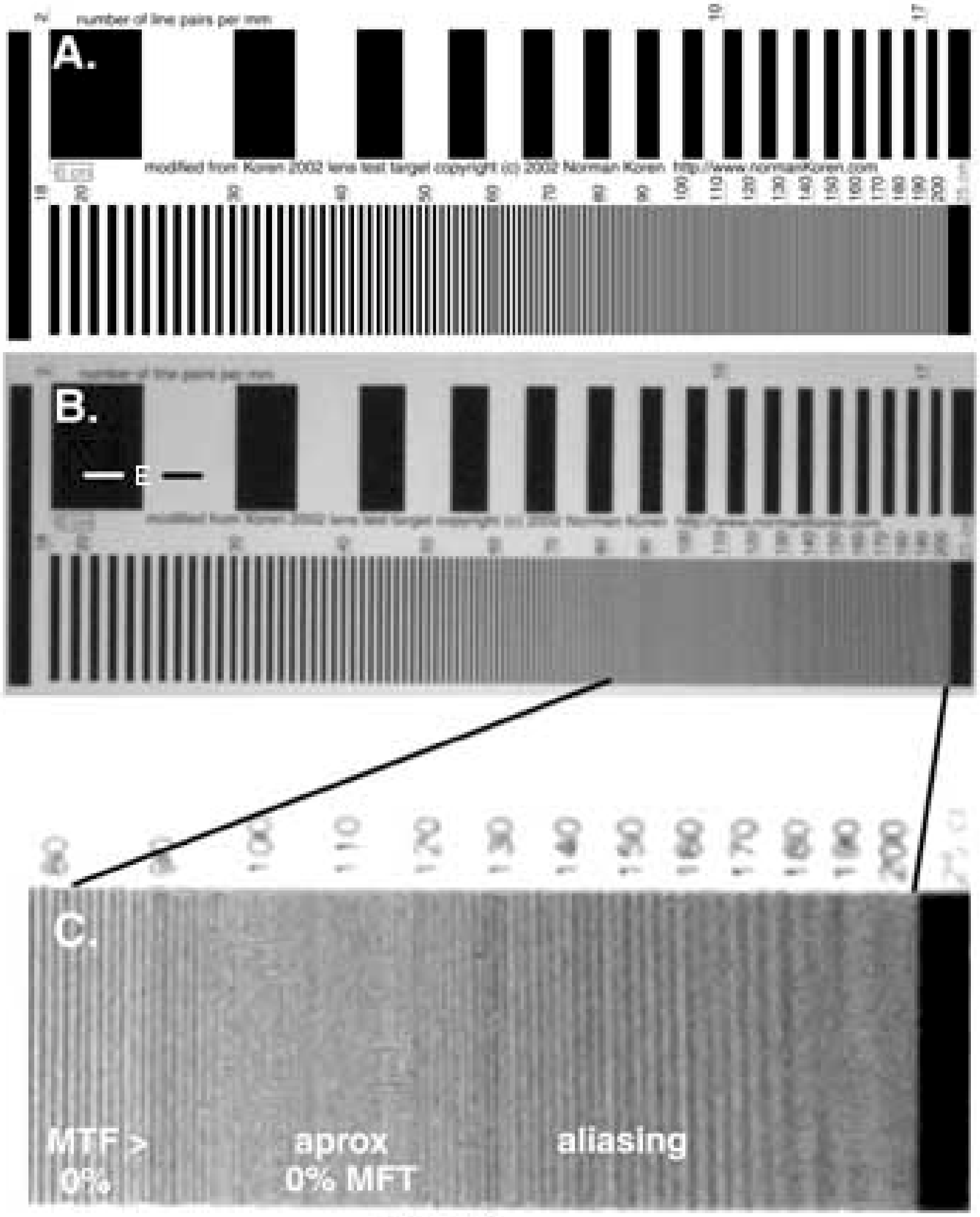
A.
number of line pairs per mm
modified from Koren 2002 lens test target copyright (c) 2002 Norman Koren http://www.normanKoren.com
B.
C.
MTF >
0%
aprox
0% MFT
aliasing

Fig. 1.

MegaPixels but a Nyquist-frequency of only 78 lp/mm. The lower frequency of the Cannon sensor compared with our Olympus chips is a result of the pixel packing density of the Cannon being lower. This results from the Cannon's pixels being spread over a 24x36 mm chip area where the Olympus pixels cover only 17.3x13mm. Of course the Canon sensor has other advantages, but not for 10% MTF lens resolution measurements ...

One notes that the the upper limits of the results of the use of 4000 DPI resolution scanner (like the one we used in our previous studies of resolution employing Tmax film images of targets captured with film cameras). Using the above formula, the limiting Nyquist Frequeny a 4000 dpi scanner would be about 78.7 lp/mm. This is the upper bond seen in lenses measured with this approach. This suggests that analysis of Olympus images of a target could potentially result in significanty larger lp/mm @ 10% MFT than obtained with scanner imaging of film images.

Taking advantage of high density digital SLR sensors offered in the future, we may be able to move well above 100 lp/mm measurements. Howeer, as digital cameras normally apply a low-pass filter to prevent aliasing, and as the physical layout of the sensor pattern also matters, the actual resolution achieved by any sensor may well be rather less.

Dividing the digital image of a resolution target into three parts.

This section describes division of a digital image into three parts based on MTF values and the Nyquist-frequency. The three zones are shown in Fig.1.C. In **Fig.1A** we give a drawing of the target which we distributed to all members of the Exakta List resolution group. You may remember it is a modification of a target devised by Norman Koren. Note that the images in Fig.1, have been adjusted for optimal contrast and maximum size to fit the plate's dimensions. **Fig.1.B** is a digital image of the target taken with a Domiplan 50mm at f5.6 (# 3769539 - M42) marked with its three areas of interest. However in Fig.1.B., these zones are difficult to see at this magnification and extreme low contrast (in some cases less than 10% of the contrast which the lens is capable of developing). To help in this regard, we have cropped Fig.1.B starting at 80lp/mm and ending at 200lp/mm. Then the cropped image was enlarged till it filled the maximum width of the figure. This enlarged view **Fig.1.C** is labelled as: > MFT% 0, about MFT and aliasing.

MTF refers to the contrast measured in gray levels (0-255) between dark and light line pairs throughout the image of the target. By definition, the maximum contrast (100% MTF) is assigned to the levels of grey measured in the largest spaced dark and white line pair (first line pair in the first row of the target, marked "E", on Fig.1.B.). As the lines become thinner (moving to the right of the upper and especially on the lower row of Fig.1.B), the dark lines appear lighter than seen in the dark line in the 100% line pair ("E", Fig.1B) and the light lines becomes darker than seen in the light line of the 100% MFT line pair. As long as dark and light lines can be seen, this portion of the image is labelled > 0% MFT (Fig.1.C). When the frequency of the lines increases in the lower row of the target where the lens or sensor cannot resolve separate separate gray levels lines, this part of the target appears largely as one shade of grey This zone is marked 0% MTF (Fig.1.C.) (no contrast between lines pairs). The last portion of Fig,1.C is lettered 'aliasing' and usually is seen in imagers of the target above the Nyquist frequency (>105 lp/mm in this case). Note that the lines in the aliasing segment are spaced by much greater distances than would be expected from an examination of Fig.1.A. Many diverse patterns may be created by aliasing. The telltale 'maze' pattern also seen on Fig.1 starting at about 90 lp/mm is frequently found in certain digital camera images. http://www.dpreview.com/learn/?/key=moire.

As to what causes aliasing we will use the digital image of the target in Fig.1 for our illustration. Consider a line pair above the Nyquist-frequency. Let us say the line pair is 110 lp/mm. Here there is room for only one pixel over this line pair. In this example, the second contiguous pixel in the sensor might be over a line pair located some distance from the 110 lp/mm line pair. Both the first and second pixel report information from their locations from different line pairs, but when this information is combined it can form an aberrant image of the target sampled (i.e. aliasing as seen in Fig.1.C). Some cameras are equipped with anti-aliasing filters, which can reduce the *appearance* of aliasing structures, but they canl also reduce resolution as well. The answer: camera sensors with higher Nyquist-frequencies.

Photographic Methods

More and more digital cameras use full 35-mm sensors (24 x 36 mm), but our Olympus cameras and others have essentially ½ frame sensors

Table I

	Dimensions	Dpi	10% MTF lp/mm
Sensor size	3648 x 2736	5.356	85.4
Raw image	3768 x 2840	5.532	88.2

(17.3x13mm), using what is called the '*four-thirds*' or 4/3 system (see: http://www.dpreview.com/learn/?/key=sensor+sizes). In resolution testing, to determine the lens to target distance for any sensor, one simply looks in "Directions" (obtainable upon request from mhiggins2814@netzero.com). Here the proper target to lens distance based on lens' focal length is given.

However, be aware that whereas the Exakta lens image circle formed in the focal plane of the digital camera really covers 24 X 36 mm, the 4/3 sensor is much smaller than this, having a diagonal of 21.64 mm which is just half the 43.27 mm diagonal of a 24 x 36 mm film frame. Therefore, the 4/3 sensor can only capture the central part of the full image circle, with the result that the digital picture looks like formed by a lens with twice the actual focal length. This ratio is commonly called the '*crop factor*', for more details see http://en.wikipedia.org/wiki/Crop_factor. For our target evaluations, this does not matter at all, as the target size on the sensor plane is so small that it fits within the area covered by a 4/3 sensor with a huge margin!

For testing, we use a tripod, to which I (MLH) attached two canvas bags full of books, 2s mirror lockup followed by 2s of time delay before exposure. I trigger an off camera an electronic flash head (the Minolta 3500xi flash) connected to the camera with two 10-m cables). OD also uses a loaded tripod, but uses halogen lights, auto exposure, and an infrared remote controlled shutter release. ISO has been set to 100, and the file format set to RAW. Take care to ensure that both the target and the camera are in a level position, as we must try to avoid rotating the digital image for level alignment afterwards. And a rightangle finder with at least 2X enlargement is a must.

Focus was found by empirically finding the best setting of the focus ring, see *"On measuring lens resolution with Exakta cameras"* by:

Determining the best focus point by eye through attaching a grating (obtained through mhiggins@2814.com; Fig.2.) at its midpoint to the focus ring at the best eye focus point. Then making several exposures with the focus ring pointing to several points above and below the grating's mid point (these exposures may be examined by means of the digital camera viewfinder at maximum magnification to reduce the number of images that need to be measured with a resolution program. In some cases ½, 1/4 or 1/3 steps of the grating need to be made to critically determine the image with the highest resolution. The best focus position is the part of the image which has the highest measured lp/mm (as a result of applying an MTF resolution program). After the best focus point is found a number of exposures should be made and analyzed to obtain the mean and standard deviation

When using a lens which is near the normal focal length, a split screen or a microraster might be helpfull in finding a starting point for beginning a focus sequence, but will introduce errors as thefocal lenght <> than 50mm Note that using a ground glass to find the approximate focus point may be difficult and subject to the errors due to a lack of correspondance between

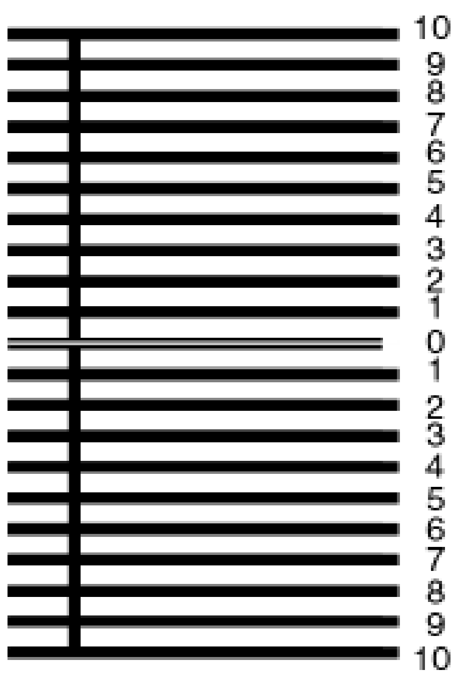

Fig.2. Gratting to be attached to focus ring of lens for aide in focusing. See "On measuring lens resolution" (obtained by request to mhiggins2814@netzero.com for more details.

viewfinder and image plain. To our surprise, we fouind more than once that what was initially believed to be the best point of focus was off by one or two grating marks (!).

Having downloaded the RAW images (called .ORF by Olympus) onto the computer, what comes next is to convert them to uncompressed greyscale TIF format. To get this right proved complicated at first, as all RAW-converters are certainly not borne equal, and if not observant it is very easy lead to an unintentionally 'enhanced image'. The biggest problem is perhaps any '*unsharp-masking*' that might be applied, as this will affect the readings, especially at higher resolutions. This problem may also be present using the traditional scanner of course, and we recommend that all helpers should as a rule be disabled.

After a while one of us (OD) settled for the freeware *IrfanView ®* program for conversion purposes (http://www.irfanview.com/). If you do, also take care to download and install the additional plug-ins, as they will be needed to be able to read the latest RAW formats.
The rest of the analysis we have done using a *Scion Image ®* to obtain a digital profile of the target, and then our own programs to ease the analyses (see below). A point worth mentioning at this stage is that we found that the pixel dimensions of the RAW image did not exactly match the sensor pixel count. The differences[7] are

not significant, but sufficient to influence the calculation of resolution to some extent (the #3769539 Domiplan at f5.6): see Table I. We have not dug deeper into this. For the time being our feeling is that the sensor size should be taken as a point of departure for calculating max Nyquist-frequency, whereas the RAW image pixel dimensions are the most appropriate for calculating max MTF resolution, as the Scion profile starts from there.

Preliminary methods and results

Ove has studied a number of lenses, but has concentrated on M42 Domiplans, 50/2.8, @f8 (with afew at f5,6) and I took the Angenieux 135/3.5 @f8 which was the focus of our last paper. The results were striking. For the 8 Domiplans in the lens resolution project, the average 10% MTF determined by film is 50.8 lp/mm at f8.0, 67.02 beeing the highest score. Using the Olympus E-400, a score of 86.6 lp/mm @10% MTF was obtained at f8.0 (the f5.6 score was better !). The Angerieux gave 63.41 +/- 2.26 lp/mm @ 10% MTF from film and 102.34 @10% MTF from digital images with the Olympus E-510. The Domiplan digital resolution figures was 29% better than the best film measurement, and the Angenieux 61% larger than my own (MLH) best film average. While these resolution figures are most impressive, they also raise a problem. The lp/mm @ 10% MTF for both these lenses taken from digital images of targets is close to the Nyquist-frequency. Thus, these resolutions may not be the actual resolution of the two lenses at 10% MTF, rather their resolution could be larger, but limited to the measured resolution because of meeting with the Nyquist-frequency.

As the Domiplan results which can be seen from Fig.1 were clearly reaching the very edge of the aliasing artifacts (others, such as an Exakta mount #4057813 Lydith 3.5/30 did the same on the E-400, scoring 87.7 lp/mm @ 10% MTF at f5.6), it could look as though the E-510 (having in effect quite another sensor) may be able to work closer to the theoretical Nyquist limit. More work will be needed to find out.

In this way of thinking, however, these lenses might have resolutions of say 150lp/mm @10% MTF, but the respective Nyquist-frequencies of the cameras used being too low to measure the true lp/mm @ 10% MTF. The question is, what do we do when the actual lens resolution might exceed the Nyquist-frequency ? Norman Koren is well known as the author of *Imatest ®*, a very advanced analysis program. I (MLH) note with interest that in his new test he does away with the 10%MTF point and uses only the lp/mm @ 50% MTF. Much can be said I favor of this approach, one of the things being that the 10%MTF end point doesn't necessarily say much about most of the pixels in a photographic image. Also if we were to measure only the lp/mm @ 50% MTF we could continue our work with relatively inexpensive digital cameras, as their Nyquist-frequencies would most likely allow the determination of most high resolution lenses at 50% MTF. It seems reasonable therefore, when using digital cameras for lens testing, to go for the 50% MTF, and I (MLH) think this should be used until its efficacy is shown. If you have other suggestions, please make them available on the Exakta list. They would be most appreciated.

Final Word

Ove and I have written programs to determine from target images the lp/mm @ 10% and 50% MTF.

In the past, film images of the target had to be sent to Philadelphia for analysis. But with the addition of digital testing it would be desirable and within reach also for individual workers to determine the resolution of their images. If you would like a copy of either (OD or MLH) program, merely direct your request to our email accounts.

Acknowledgements: We are very grateful to Miles Upton for placing this and other resolution reports on his web site, to Mark Stuecheliand and Hugo Ruys for looking over the preprint, and for Hugo suggesting corrections. This paper is for free circulation. Please share it with anyone or any organization.