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Evaluating Commercial Scanners for Astronomical Image Digitization

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Abstract. Many organizations have been interested in understanding if commercially available scanners are adequate for scientifically useful digitization. These scanners range in price from a few hundred to a few tens of thousands of dollars (USD), often with little apparent difference in performance specifications. This paper describes why the underlying technology used in flatbed scanners tends to effectively limit resolutions to the 600-1200 dots per inch (dpi) range and how the overall system Modulation Transfer Function (MTF) can be used to evaluate the quality of the digitized data for the small feature sizes found in astronomical images.

Two scanners, the Epson V750 flatbed scanner and the Nikon Cool Scan 9000ED film strip scanner, are evaluated through their Modulation Transfer Functions (MTF). The MTF of the Harvard DASCH scanner is also shown for comparison. The particular goal of this evaluation was to understand if the scanners could be used for digitizing spectral plates at the University of Toronto. The plates of primary interest were about 15 mm (5/8 inch) wide by 180 mm (7 inches) long and ∼50 mm x 80 mm (2 x 3 inches).

The results of the MTF work show that the Epson scanner, despite claims of high resolution, is of limited value for scientific imaging of feature sizes below about 50 μm and therefore not a good candidate for digitizing the spectral plates and problematic for scanning direct plates. The Nikon scanner is better and, except for some frustrating limitations in its software, its performance seems to hold promise as a digitizer for spectral plates in the University of Toronto collection.

1 Introduction

Many organizations have expressed interest in using commercially available flatbed scanners to digitize astrophotographic plate collections. These scanners range in price from a few hundred to a few tens of thousands of dollars (USD) often with little apparent difference in performance specifications. This paper is an attempt to quantitatively measure the optical and digitization performance of several scanners to help answer questions about their usefulness for such projects, with a particular focus on using them for spectrographic plates. The plates of particular interest are those at the University of Toronto which are ∼15 mm (5/8 inch) wide by 180 mm (7 inches) long and ∼50 mm x 80 mm (2 x 3 inches).

The two scanners selected for evaluation were the Epson V750 flatbed scanner, which has seen use in Europe at several locations and can do up to 8.5 x 11.7 inches (216 x 297 mm) plates, and a Nikon Cool Scan 9000ED film scanner that is designed for 35 mm and 6 x 7 cm medium format film and film strips and has a 6 x 88 cm total scan area. Both claim resolutions in the 4000-4800 pixel range. Three other scanners were also subjected to the same analysis, the DASCH digitizer (a custom designed machine being used to digitize the Harvard College Observatory plate collection[1]), a MicroTek i800 scanner in use at the Pisgah Astronomical Research Institute (PARI), and a Umax PowerLook 3000 scanner at Harvard, to provide some other perspectives.

This study, sponsored by the Department of Astronomy and Astrophysics, University of Toronto, was conducted in two parts with separate investigators. This paper focuses on finding quantifiable measures of scanner optical and digitization performance. In a companion paper, Ian Shelton focuses on doing science with the digitized data from the Nikon scanner and comparing that to previous work done with a PDS 1010 digital microdensitometer.

2 Finding Ways to Quantify Scanner Performance

2.1 The Underlying Technology of the Scanners: Pixel Sizes

The heart of a commercial scanner is a linear CCD array. Historicaly these arrays were three lines of pixels with on chip color filters for red, green, and blue which allows scanning of colored items. The color filters may also include a micro lens (to focus the light over the channel stopper area onto the active area) that makes the fill factor for each pixel close to 100%.

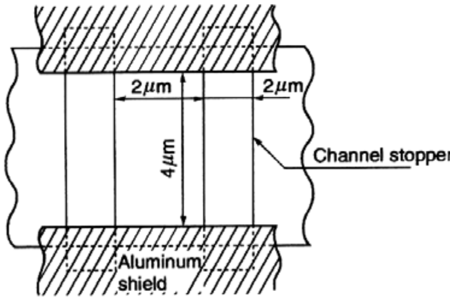
The X-Y dimensions of the pixels are limited by the conflicting physical problems of dealing with the long, thin silicon die that result from the large number of pixels in the lines and the desire to have a large active area for each pixel to achieve true dynamic range. For practical reasons associated with cutting and attaching long narrow chips to a package so that it is electrically and optically correct, early die sizes were limited to being about 35 - 50 mm long and a generally 2 mm wide. Recently, some of the vendors are able to deal with longer die (∼75 mm long) for the high-end scanner market.

Since the length of the die is limited and the number of pixels needed to cover the maximum scan width (typically 8.5 inches) is fixed for a given dots per inch (dpi), the width of the pixel is limited to what can fit into the ∼40 mm maximum active die length. Figure 1a shows the pixel size for an NEC 1200 dpi scanner chip (4μm [2 μm active] x 4 μm).

To achieve 1200 dpi over the 8.5 inches of the flatbed scanner platen, the chip must have 8.5 x 1200 or 10,200 active pixels in the line. There are also some dark pixels at each end of the line and a few invalid pixels at each end as well, so that typically there might be an additional 50-64 pixels in a line that are not used for imaging. So if we assume that the total line is 10,300-10,600 pixels, at 4 microns per pixel the length of the active pixels is ∼40.8 mm, the length of the whole array is ∼42.4 mm and the die itself may be ∼50 mm, which is typical of many linear CCD arrays used for flat bed scanners.

The optics of the scanner must map a pixel on the 40.8 mm active line length onto a virtual pixel on the 8.5-inch length of the scanner. That means that the

[1] `http://tdc-www.harvard.edu/plates/`



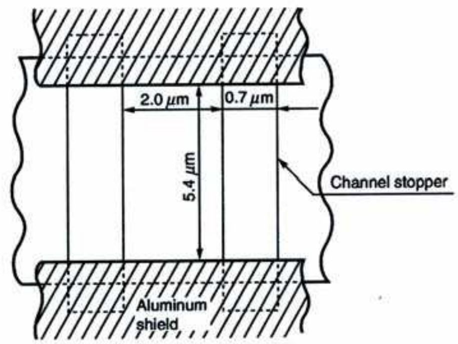


Figure 1. **(a)** The left diagram shows the pixel dimensions of a NEC UPD 8870 chip. **(b)** The right diagram shows the dimensions for many more recent NEC CCDs.

lens in the scanner will reduce the 8.5 inches, or 216 mm, length to 40.8 mm so the lens has a magnification of ∼5.29x from the chip pixel perspective. This translates the 4 μm x 4 μm pixel of the chip of Figure 1a to an effective pixel of 21.2 μm x 21.2 μm at the scanner platen.

Figure 1b shows a pixel size in use by a number of more modern scanner chips. The channel stop is reduced from 2 μm to 0.7 μm, giving an X value of 2.7 μm, and the Y value of the pixel is increased from 4 μm to 5.4 μm. This means the photon gathering area is increased from 8 square microns to 14.6 square microns giving the well 1.8 times more area which results in a better dynamic range - one of the marketing features of most recent scanners.

A 1200 dpi scanner chip with the more recent pixel size would be 10,200 x 2.7 μm or 27.54 mm of active length. This smaller chip length makes the CCD less expensive. However the lens system must now magnify by 7.84x (rather than 5.29x) to fill the 8.5 inch platen, and the effective pixel size become 21.6 μm x 42.3 μm and has X-Y asymmetry.

The least expensive of today's scanners typically claim 2400 dpi and high-end scanners are claiming 4800-6400 dpi. How can they do this and stay within the limits imposed by silicon and packaging technology? The answer is that they overlap rows of pixels (see Figure 2) which are approximately the 1200 dpi size and construct "sub pixels" at the "higher" resolution. Scanner software can construct a "virtual" pixel array that takes "real" pixel values and uses them to interpolate values for intermediate "non-optical" pixels. By using overlapped pixels, the actual values of the "real" overlapping pixels can be used instead of a linear interpolation (which was how earlier scanners made resolution claims). This way the interpolation can be non-linear and bear more relation to non linearities in the image.

The most common overlap is to have two rows of pixels for each of the three primary RGB colors. This is often called a six line sensor. There is an on-chip color filter covering the dual pixel rows for each color.[2]

[2] One NEC chip (UDP 8884) actually has 4 overlapping rows, with each row one-quarter of a pixel offset from the adjacent rows.

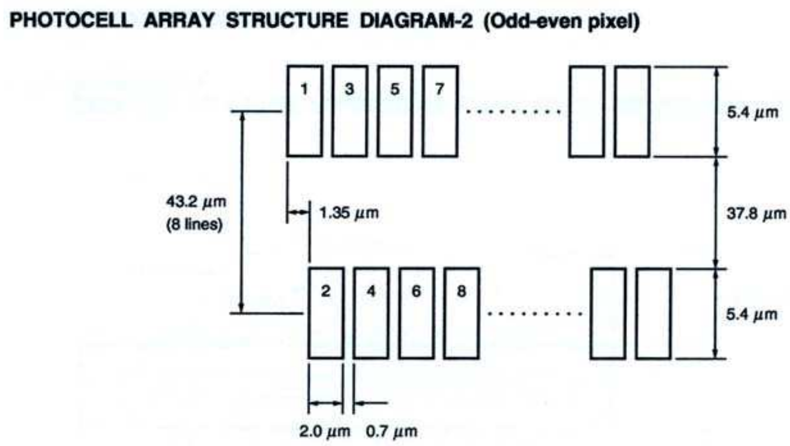


Figure 2. Overlapped pixel structure.

This two row overlapping allows a chip that has actual pixel sizes appropriate for 1200 dpi to claim to be a 2400 dpi scanner, because it "really" has that number of pixels even though the CCD has the same small die length. The problem, of course, is that the pixels are not looking at independent areas of the real image and so are not able to contribute high frequency information to the final digitized image. One advantage of this approach, though, is that it simulates the action of an anti-alias filter, which tends to reduce Moiré patterns caused by the interaction of image detail with the pixel array.

Figure 3 uses shading to show how two rows of overlapping pixels can be combined to generate twice as many sub-pixels. The bottom row shows the sub-pixels and the colors in those show the source of data for each sub-pixel. Each sub-pixel gets half of its data value from each of the two pixels that overlap to form the sub-pixel. Note that in the Y direction the process is similar, but in many cases the actual physical pixel is twice as long in the Y direction to begin with. However, the mechanical stepping motor system can step in sub-pixel increments in the Y direction, often in much finer increments than even the sub-pixel in the X direction. Sub-pixels can be constructed in the Y direction as well, but they will generally have less "true" spatial resolution in Y because the true "optical" pixel is longer in that direction. The sub-pixels are just optical pixels that have been divided into multiple "virtual" pixels with the same value. The values can only change in a meaningful way when the sub-pixel crosses between the boundaries of two optical pixels.

2.2 Considerations for Digitizing Spectral Plates

We wanted to evaluate two particular scanners, the Epson V750 and the Nikon 9000 ED film scanner, to see if they could be suitable for digitizing the plates of astronomical spectra at the University of Toronto. In particular, we wanted eventually to compare the digitizing results with those attainable with a PDS machine.

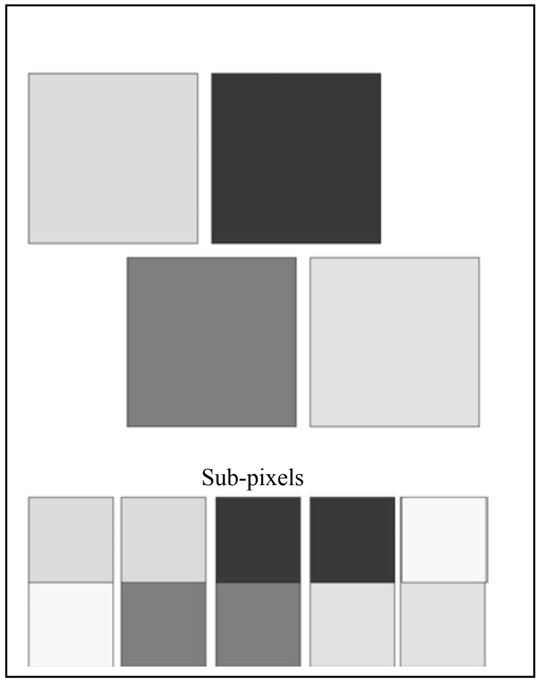


Figure 3. Making Sub-Pixels.

The Epson scanner claims a resolution of 4800 dpi over an 8.5 inch width and 6400 dpi over a 5.9 inch width and has two lenses which are moved by motor into place for the two different resolutions. The Epson scanner can step over an 11.5-inch length in the Y direction and claims 12,800 dpi in the Y direction, indicating that the minimum mechanical step is about 2 μm. The Epson scanner specifications indicate a CCD with 6 lines and 122,400 pixels in the 4800 dpi mode and 6 lines with 113,280 pixels for the 6400 dpi mode.

The Epson scanner claims 16 bit digitizing, and indeed it has a 16 bit A/D converter. However the number of electrons that a full well can hold is probably on the order of 30,000 - 40,000 electrons, which means that each electron would represent $\sim$two bits in the converter. The reality is most of the low order bits out of the 16 bit converter are noise from the electronics and the pixel wells really support only about 8-9 bits of real distinguishable information.

The Nikon film scanner claims 4000 dpi over a 6 cm width and has a stepping limit of 90 cm. The Nikon scanner indicates that they use a 10,000 pixel 3-line CCD (with no color filters since they control color with LED lighting sources). One paper (Henderson et al. 2007) and Nikon specs indicate that the effective pixel size for the Nikon is 6.35 μm x 6.35 μm, but the same paper shows MTF results (see Figure 3 in that paper) for the Nikon scanner that indicates the X and Y dimensions of the effective pixel are rectangular and not square.

It was necessary to do some detective work to get a better idea what the true optical pixel size is for both scanners.

3 The Epson Scanner Hardware

I managed to get a broken Epson V700 scanner on eBay so that it could be taken apart to understand how the machine was constructed and, particularly, to understand more about the linear CCD chip used. The major features of that scanner are identical with the V750 that would be used for the tests on actual spectra except that the V750 optics have anti-reflection coatings and there is more software (V750 literature).[3]

Taking the device apart to get at the actual CCD array enabled measuring the total array length at about 56.8 mm (the part covered with the RGB filters and measured through the glass window) with a precision caliper. The overall length of the package for the device is 71 mm.

Since the specifications indicated a 6-line 122,400 pixel array, the length of a line should be 122,400 ÷ 6 or 20,400 pixels. If the pixels were of the 2.7 μm x 5.4 μm variety that seems in general use at NEC, then the active line length would be 55.08 mm and extra dark pixels and room for amplifiers can easily account for the additional measured ~1.8 mm. The measured array length is then quite consistent with an X pixel dimension of 2.7 μm. Given that the Epson scanner also touts having a wide dynamic range it is also seems likely that they are using a Y pixel dimension that is greater than the X dimension and so an initial assumption for this scanner is that it uses the 2.7 μm x 5.4 μm silicon pixel dimensions common to many NEC linear CCD chips.

An imaging system to convert 8.5 inches to 55.08 mm would have a magnification of 3.922. This would lead to an effective pixel size of 10.59 μm x 21.18 μm in the 4800 dpi mode. This effective pixel size assumes that a cylindrical microlens on the array fills in the channel stop area perfectly without elongating the Y direction (private Epson correspondence indicates that they use a micro lens on this array).

A true 4800 dpi pixel would be 1 inch = 25.4 mm ÷ 4800 or a 5.29 μm square. By overlapping each of the larger pixels with another row of pixels, Epson can create sub-pixels of 10.29/2, or the 5.29 μm which has the same dimension as a true 4800 dpi 100% fill factor pixel in the X direction. But this means that without overlap, the optical resolution of the Epson scanner in the X direction is 2400 dpi. In the Y direction, the optical pixel is 21.18 μm long. This is ~4 times the length of a true 4800 dpi pixel. Sub-pixel steps in the Y direction (4 must be generated rather than the 2 in the X direction) will result in many sub-pixels with the same values since they will be constructed using partial data from the same set of physical silicon pixels. There is simply less "real" information to work with in the Y direction. This is why many scanners will not have the same spatial resolution in the X and Y scan directions. The Y direction specifications are often higher because they simply reflect the scanners ability to mechanically step the optics, but since the actual pixel length in that direction is larger, the specifications are essentially misleading.

The Epson scanner has two lens systems and switches between them. The primary lens system is for the 4800 dpi mode and covers the full 8.5-in width of the platen. The 3200/6400 dpi lens system covers only 5.9 inches and claims

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[3] See `http://www.imaging-resource.com/SCAN/V700/V700.HTM`

113,280 pixels across that area. The claimed 113,280 pixels ÷ 6 equals 18,880 pixels per line, which divided by 5.9 inches gives 3200 pixels per inch. A lens system with a magnification 2.94x would accomplish this and would project a pixel size of 7.94 μm by 15.88 μm at the platen.

4 Measuring the Performance of a Scanner

Capturing an image from a film can not be perfect. To understand some of the issues involved it is helpful to understand the concept of Modulation Transfer Function (MTF). MTF is a measure of the preservation of contrast throughout an optical system. As the MTF percentage goes down, the white and black values both tend toward gray and the edges of an imaged object become blurred. Eventually high frequency information in the image is lost. Perceptually this occurs for most people around an MTF of 10%. MTF is an important measure of the quality of the optical system and the way the optical system interacts with the CCD sensor to achieve resolution.

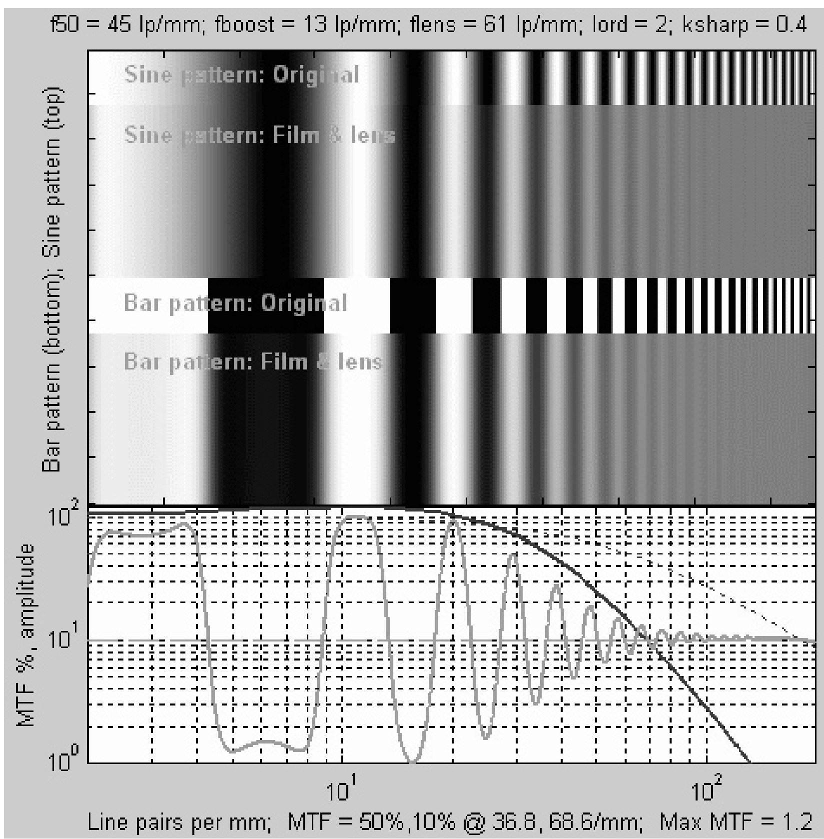

Figure 4. Illustrating MTF (courtesy of Imatest).

Figure 4 shows the effects of an optical system imaging a pattern of ever decreasing line and space sizes. Because any optical system will introduce some blurring of the edge of the lines, as shown in the figure, as the lines and spaces get smaller, the blurring begins to fill in the spaces and contrast is lost until it is no longer possible to distinguish lines and spaces. Figure 5 shows visually the effects of MTF on a sine pattern of decreasing line width and spacing.

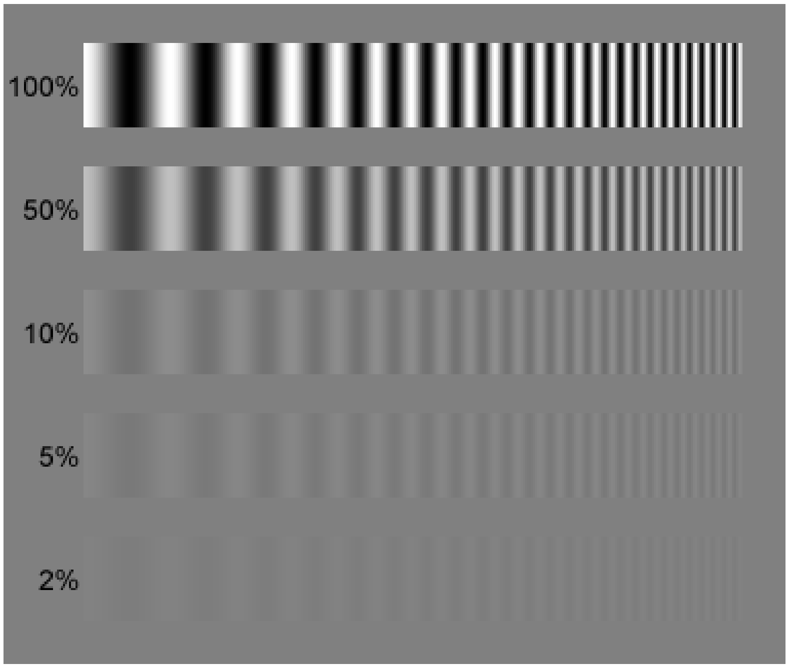

Figure 5. Contrast and resolution.

4.1 Sensor MTF: Pixel - Image Interaction

A good description of how pixel size can interact with an image to produce false image detail when digitizing is given on an Imatest^{TM} web page.[4] We quote part of the description here.

> The Nyquist sampling theorem states that if a signal is sampled at a rate *dscan* and is strictly band-limited at a cutoff frequency f_C no higher than *dscan*/2, the original analog signal can be perfectly reconstructed. The frequency $f_N = dscan/2$ is called the ***Nyquist frequency***. For example, in a digital camera with 5 micron pixel spacing, $dscan = 200$ pixels per mm or 5080 pixels per inch. Nyquist frequency is $f_N = 100$ line pairs per mm or 2540 line pairs per inch.
>
> The first sensor null (the frequency where a complete cycle of the signal covers one sample, hence must be zero regardless of phase) is ***twice*** the Nyquist frequency. The sensor's average response (the average of all sampling phases) at the Nyquist frequency can be quite large.

[4] `http://www.normankoren.com/Tutorials/MTF2.html#Nyquist`. Reproduced by kind permission of Norman Koren, Imatest.

Signal energy above f_N is ***aliased*** – it appears as artificial low frequency signals in repetitive patterns, typically visible as Moiré patterns. In non-repetitive patterns aliasing appears as jagged diagonal lines – "the jaggies." Aliasing is visible in some of the small boxes in this article where bands of high spatial frequency interact with the low sampling rate of the monitor screen, roughly 80 pixels per inch.

In this simplified example [shown here in Figure 6], sensor pixels are shown as alternating white and cyan [gray in Figure 6] zones in the middle row. By definition, the Nyquist frequency is 1 cycle in 2 pixels. The signal (top row; 3 cycles in 4 pixels) is 3/2 the Nyquist frequency, but the sensor response (bottom row) is half the Nyquist frequency (1 cycle in 4 pixels) - the ***wrong*** frequency. It is ***aliased***.

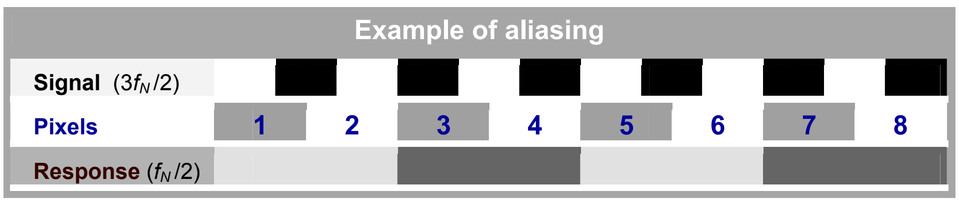

Figure 6. An example of how signal frequency and pixel size can produce aliasing.

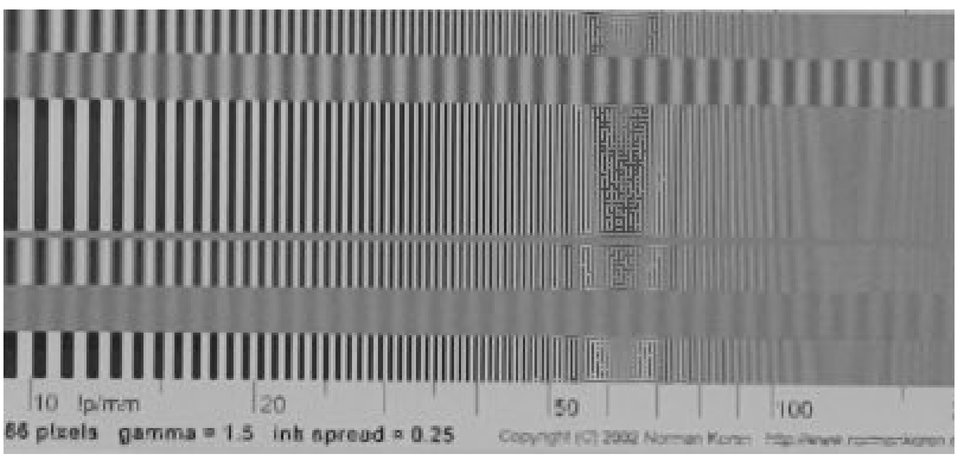

Figure 7. An illustration of aliasing.

If the optical MTF is good beyond the Nyquist frequency and there is high frequency content in the image, then there may be image detail beyond the Nyquist that seems real, but that detail is constructed from out-of-phase images and is called an alias image.

Figure 7 illustrates how high frequency alias content can generate problems if the image is not effectively low pass filtered at or below the Nyquist frequency. In the scanners that have overlapped pixels, the overlap would seem to have the effect of providing some anti-aliasing filtering as well as allowing claims of greater resolution.

While the Nyquist frequency of 1 cycle in 2 pixels will accurately reproduce a signal that is in phase with the pixels, it is better to use 3 pixels to sample one cycle which also allows for images with any phase shift from the pixel array to be accurately reproduced. This therefore suggests that a more realistic criterion for the highest frequency that can be reliably detected is 2/3 the Nyquist frequency.

5 Measuring the System MTF: (Sensor and Lens)

The MTF of a scanner system can be measured by the slanted edge method of calculation. A sharp edge is imaged at a small angle to the line of the sensor array. Looking across the line of sensor pixels, each pixel will see a black to white transition occurring at a different point than the adjacent pixel and so will have a different grey level. The computational technique then looks at the way the sensors in the line see the different gray levels (fill levels of the wells) in the sensor pixels and compares that to the theoretical behavior of a perfect imaging and sensing system. This approach was developed by Don Williams of Kodak and is described in International Organization for Standardization (ISO) standard 12233. Norman Koren has developed this technique into a sophisticated tool suite called Imatest^{TM} and he graciously supplied us with it to enable us to evaluate scanners.

Our testing was done by scanning a high quality chrome-on-glass U.S. Air Force 1951 Resolution Test Pattern target that has a series of well defined and measured orthogonal lines and spaces. For this particular test what we wanted was just a very straight sharp edge in both the horizontal and vertical directions (which the target provides) so that we could look at the MTF in the X and Y directions of the scanner. The X direction is considered the short axis of the scanner and is the one that the linear CCD pixels are aligned to. The Y direction is considered the long axis of the scanner and is the one that the mechanical scanning occurs in. The target is tilted slightly on the platen so that in both directions the sharp edges of the image are at a slight angle to the X and Y directions of the scanner. Once the scan is complete, the software allows selecting an edge for either X or Y evaluation.

5.1 The DASCH Scanner

Figure 8 shows the results of an analysis for the DASCH digitizer which uses an area array of 4096 x 4096 pixels (rather than a linear CCD) imaging with a telecentric lens set to f/5.3 that digitizes the image with true 12-bit accuracy. The horizontal line of the target is used to understand the vertical profile. The top plot shows the sharpness of the edge seen through the optical system. In this case the blurring at the sharp edge is less than two pixels. The lower plot shows the MTF % vs. the line pair cycles. On this plot I have highlighted three different points: the sensor Nyquist frequency, 1/2x the Nyquist frequency, and 1/3x the Nyquist frequency. These correspond to feature sizes of 11, 22, and 33 microns respectively.

To understand the feature sizes needed to capture all the information in astronomical images, we need to know what developed image sizes are likely to

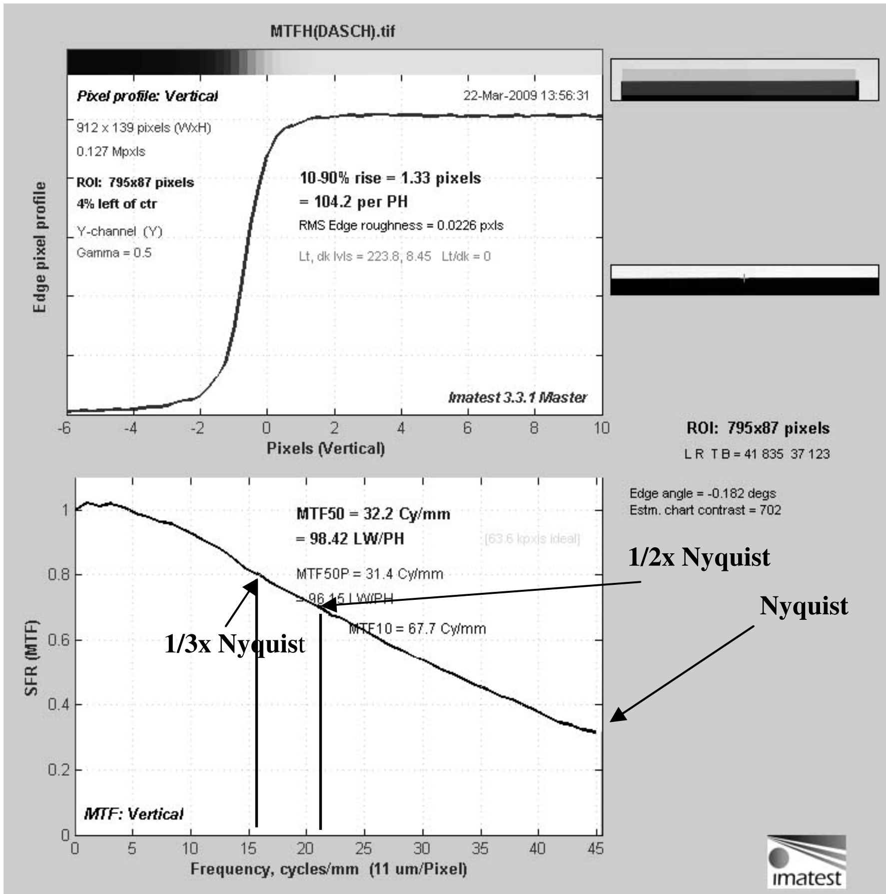

Figure 8. MTF vertical profiles for the DASCH scanner.

be on the emulsion. For direct plates we can look at the Airy disk size. For a discussion of this see the web page Catching the Light (Focusing: Definitions and Formulas) by Jerry Lodriguss.[5] Figure 9 shows the Airy disk size for optical systems of differing f-numbers. For the Harvard Observatory collection, most of the plates were taken with telescopes of long focal length. The image diameters in Figure 9 are ideal numbers; the actual star diameters on plates are affected by focus, atmospheric turbulence, the brightness of the stars, and the exposure time for the plate. For design purposes we used the diameter of $\sim$30 μm as the likely smallest star image that can be discernible on the Harvard direct plates. This is close to 1/3 of the Nyquist frequency for our 11 μm sensor (which ensures that the smallest images will be sampled at least three times in any given direction) and so it is appropriate to use that value for contrast degradation.

The Airy disk of the lens for the scanner is also going to limit resolution. To have a scanner with very high resolution, it would be necessary to have a

[5] `http://www.astropix.com/HTML/I_ASTROP/FOCUS/DEFS.HTM`

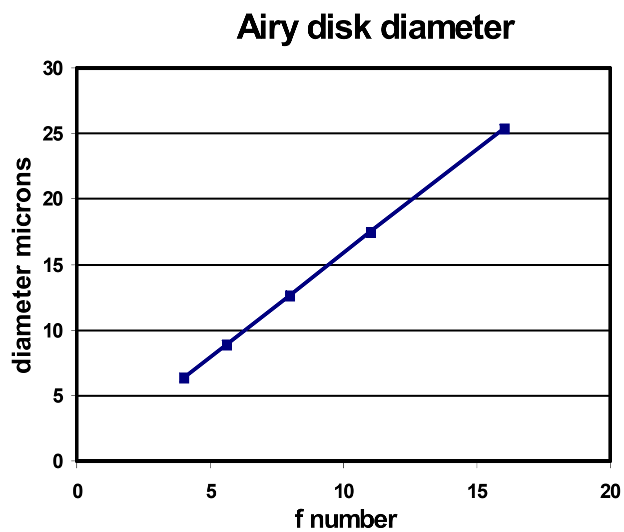

Figure 9. Airy disk diameter as a function of f-ratio.

very fast lens which is more likely the case on dedicated film scanners than flat bed scanners. For the DASCH machine we use a telecentric lens which images 1:1 and is f/5.3, which provides an Airy disk less than the pixel size of 11 μm.

The MTF shows what happens to contrast for a series of light and dark line features. In that sense it is one dimensional. This is a good match for the case of spectral lines but not for star images. To get a sense of what happens in a two dimensional figure like a star, a simplified approach is to treat the star as a square and multiply the X and Y MTF percentages. For the DASCH machine, which has square pixels (the measured MTF is essentially identical in both directions confirming the square pixel), this simple method indicates that, for the smallest star image, the contrast of the digitally scanned star image will be degraded by 0.8 x 0.8 or to about 2/3 of what is on the plate.

5.2 The Epson Scanner

Now let us look at the Epson scanner. From the discussion above, to scan a typical 8 x 10-inch direct plate or a spectrum larger than the 5.9 inches that is the limit for 3200 dpi scanning, the native, non-overlapping pixel is a 2400 dpi one. The pixel size is 10.59 μm x 21.18 μm. This means that we need to look at the MTF in both the X and the Y directions.

In Figure 10 you can see the measured MTF for the Epson scanner in the 2400 dpi mode. There is some, but not a lot, of difference between the X and Y directions. I believe this is because the MTF is dominated by the lens system in this machine. In fact, in the 3200 dpi mode the MTF is little different as well but shows more difference in the X and Y directions. The lens system makes the claims of high resolution rather a mute point because apparently the two lens systems do not have the MTF to support the resolutions that the chip pixels might otherwise achieve. If we look at the contrast for a "star" image (a 30 μm feature size), the Epson will give approximately 0.4 x 0.4, or 0.16, the original contrast compared to the ∼0.66 for the DASCH machine. Figure 11 shows a scan of the same area of a direct plate of a star field to illustrate the difference in contrast and detail preservation.

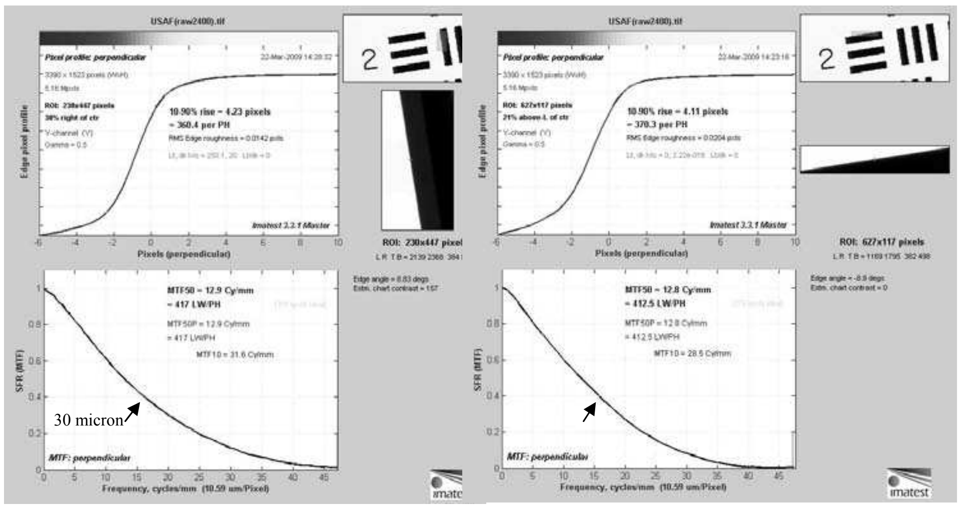

Figure 10. The MTF in X and in Y for the Epson V750.

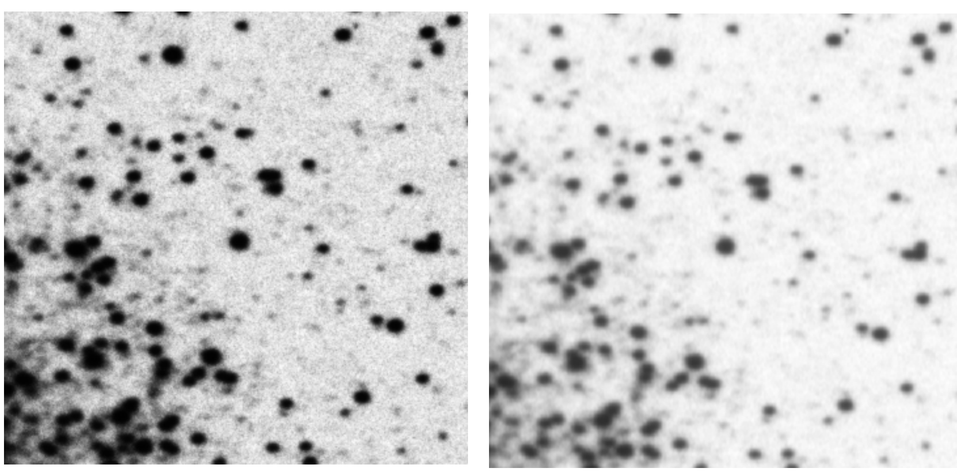

Figure 11. Comparison of results from the DASCH and the Epson scanners.

5.3 The Nikon Scanner

The other scanner that we evaluated was the Nikon Cool Scan 9000 film strip scanner. This machine is designed to scan 35-mm slide film in strips. Unfortunately, the software for this machine only allows scanning in the areas where it expects to see a 35-mm frame. Therefore, long spectra plates had to be scanned in sections and then moved to capture the skipped over areas. This greatly increases the scan time as long spectra plates had to be scanned in sections and then moved to capture the skipped over areas, and the results had to be spliced together or analyzed in pieces. Another problem is that the linear CCD for this machine is, as is typical, oriented along the X axis while the scanner format requires that the plate be scanned in the Y direction. This greatly increases the scan time because the scanner must mechanically step and then integrate for a few milliseconds for each pixel and also has the effect of using the least good axis from an MTF standpoint.

Figure 12 shows the MTF measurements for the Nikon scanner. Notice the significant difference between the X direction on the left and the Y direction on the right. The scanner specifications indicated a square pixel at 6.35 micron (4000 dpi). However, the arrows in Figure 12 show the location of the 1/3 x Nyquist frequency for the Nikon stated pixel size and it is clearly significantly different in the X (0.8) and Y (0.65) directions. The most logical explanation for this is that the pixels are not square but are, in fact, longer in the Y direction.

This would indicate that the pixel size at the chip focus of the lens system is perhaps 6.35 x 7.8 μm. The lens system for the Nikon appears to be significantly better than the Epson and in the X direction supports the MTF to achieve the resolution of the CCD with some contrast. Unfortunately the Y direction must be used for scanning the lines and spaces of the spectra plates. Still, the overall MTF of the Nikon is significantly better than the Epson and would appear to be a better choice to use for scanning spectra.

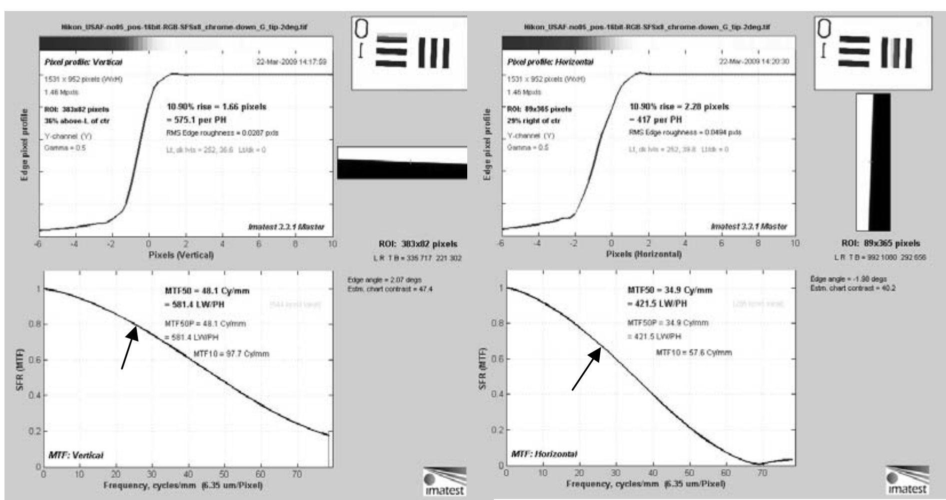

Figure 12. The MTF of the Nikon Cool Scan 9000ED.

Another way to look at this is to observe the line and space feature size that each machine's lens can capture with 50% of the contrast of the original. For the DASCH machine this is 15.9 microns (less than the 33 μm sensor/lens limit), for the Nikon it is 14.3 microns (less than its 19.05 μm sensor/lens limit), and for the Epson it is 39 microns (greater than its 31.77 μm sensor/lens limit). The Epson lens effectively limits that scanner to something between 1200 and 2400 dpi resolution.

6 Foiled by Scanner Internal Processing

I had the opportunity to test two other flatbed scanners, a Microtek i800 and a Umax PowerLook 3000 scanner. Both of these scanners apparently do some internal processing that heavily clips the white levels and/or the black levels which effectively compresses the dynamic range. This makes any MTF analysis rather unreliable because it is the variety of different pixel values near the sharp edge that are used in the calculations. If this information is preprocessed to enhance edges, or compress the dynamic range, then the analysis tends to indicate better system performance than is really achieved and it distorts the digitized image affecting further analysis methods that want to use the raw data from the scanner.

Figure 13 shows the asymmetry between the Y and X scan directions for the MicroTek scanner and the white level clipping that makes the analysis questionable. This clipping would also affect the scientific usefulness of the resulting scan data because the true shape of the point spread function (psf) of the gray level distribution of a star as captured on the film will be distorted in the digitization process. Star magnitude determinations are highly dependent on the diameter of the image and the analysis of the psf of the star image which, if distorted by clipping of the white level, will result in destroying the information which is most useful. This kind of processing, that may make color photographs look better, unfortunately can corrupt further processing desirable for scientific purposes. In many scanners it seems to be difficult or impossible to turn off this processing.

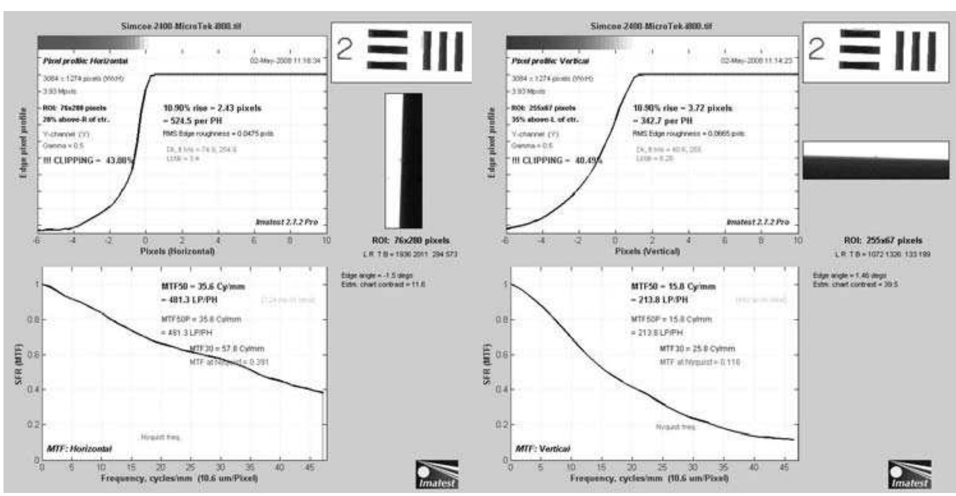

Figure 13. The asymetry between X and Y for the MicroTek scanner.

7 Conclusions

Specifications for commercial scanners are very misleading and not at all a good indication of what the scanner can do with scientific images. Most commercially available flat bed scanners achieve high resolutions specifications by using multiple line CCDs that have an overlapping pixel structure and counting mechanical stepping capability as resolution. These "specmanship" games blur the real capability of the scanners. The tradeoffs in the lens systems that are used to reduce the pixels at the platen to the pixel size of the chip, and also to have a reasonable depth of focus, often result in an MTF for the system that really keeps true effective resolutions of the flatbed class of scanner to the 600-1200 dpi region. A/D conversion bits are also substituted for the actual realistic dynamic range that the pixels and electronics support. For the few specialized film strip scanners that are available, the lens systems can be better because they do not need to have a wide field and they can be faster. But this type of scanner is only potentially good for scanning long narrow spectral plates or other small plates that fit within the design format for the film strip class scanner (e.g. 6 cm x 90 cm).

All of this leads to the conclusion that while digitization with current commercial or comsumer flat bed scanners can provide electronic access to the information on the direct or spectral plates scanned with them, the resulting images do not capture adequately the true quality of what is in the emulsion. This is especially true for direct plate images. The scans are not really good enough to do justice to the images that are on the plates even though some science can be done with them. The images they produce are perhaps most valuable as metadata that can be electronically accessed to see if the plates may have data on them useful for a particular scientific inquiry. Others have shown that commercial flatbed scanners typically have periodic position errors that make astronomic measurements difficult (Vicente, Abad, & Garzón 2000; Carlin, Majewski, & Patterson 2006). This work confirms that these scanners can also have sharp fall off of MTF which reduce contrast significantly for image details of interest for both direct and spectral plates. Similar conclusions were expressed in the paper "The D4A Digitizer" by De Cuyper, Winter, & Zacharias (2006), which shows actual scans of a high quality target and illustrates the effects of MTF fall off at high frequencies in some other commercial scanners.

For spectral images, the Nikon Cool Scan 9000 ED scanner actually seems to be reasonably good. Even though the form factor of the spectral plates forces scanning in the direction with the lowest resolution, the lens system does not need as much magnification and is likely of higher quality because this class of film scanner commands a higher price point in the market. Ian Shelton discusses his results comparing the reduced data from this scanner to data from a PDS machine in the companion paper that follows.

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