Scanning with CCDs and PMTs

The recent introduction of the TOPAZ™ scanner, plus the proliferation over the past few years of other CCD flatbed scanners (including the Linotype-Hell Chromagraph® S2000), has opened a discussion on quality issues for different kinds of scanners. And really, this discussion can be framed as a comparison of the high-end repro versus desktop, drum versus flatbed, or CCD versus PMT.[1] It all comes down to this question: Can CCD scanners produce the same quality scans as PMT scanners?

[1] CCD stands for charged-coupled device. PMT stands for photomultiplier tube.

In this article we will look at some of the important quality issues related to CCD scanning, and see how the quality gap has narrowed between CCDs and PMTs. It will become clear, however, that whether a scanner uses CCDs or PMTs may not be the most important consideration. What is most important is how the technology is implemented in the scanner, and how that affects quality, enlargement, and productivity.

CCDs & PMTs

CCDs and PMTs are the devices that record the color or tonal value of an original and turn it into a numerical value. All color scanners record these values as components of red, green, and blue (RGB). Afterwards, the values may be manipulated as RGB, or, converted to another color space perhaps CMYK (cyan, magenta, yellow, and black) or one of the CIE color spaces.[2] For example, TOPAZ (in conjunction with LinoColor 3.2) captures images in RGB and immediately converts them into a CIE color space, CIE LAB.

[2] For more information on CIE color spaces, please refer to the Linotype-Hell Technical Information article entitled *Color Space Conversion* in the 1992 notebook.

PMTs have been used by most of the high-end scanner vendors in their products. As a result, PMT technology is generally associated with high quality color scanning (sometimes referred to as “repro”). CCDs are used in a wide range of devices from video cameras to desktop scanners, but they are also used in high quality scanners like TOPAZ. While many people associate CCDs with the low end of the quality spectrum, CCDs have generally provided good quality at a reasonable price. And, as the technology has matured, so has the quality. Today’s CCDs have improved immensely over their predecessors.

PMTs are used in drum scanners while CCDs are used in flatbed scanners. As a rule, you can assume that a drum scanner contains PMTs and a flatbed scanner contains CCDs (even when it is not specifically mentioned).

Inside a scanner

A typical CCD scanner has a flat bed, usually glass, on which the original is placed. The CCDs are arranged in a line.[3] Upon scanning, one of two things happens, either the flatbed is moved past the line of CCDs, or, the line of CCDs is moved and the flatbed remains stationary.

[3] In a digital camera, the CCD array is made up of many rows and columns of CCD elements.

In a drum scanner, the original is attached to a drum which spins while a moving recording head reads the color or tonal values of the original. The photomultiplier itself is a vacuum tube. The light from the image hits the tube at which point the light is converted into electricity. This electrical signal is strengthened (i.e., multiplied), and the strengthened signal is what is used. This ‘multiplication’ is one reason why PMTs generally are able to capture a larger density range than CCDs.

Linotype-Hell Scanner Comparison

Scanner name	Capture technology	Max. spatial resolution	Tonal resolution	Density range	Scaling range	Maximum size of original
S2000	Flatbed CCD	8,000 ppi	14 bits per color	3.2	20-2000%*	5.1” x 14” (trans.) 9.9” x 14.2” (refl.)
TOPAZ	Flatbed CCD	8,000 ppi	16 bits per color	3.7	20-2000%	8” x 10” (trans.) 12” x 18” (refl.)
S3300	Drum PMT	10,000 ppi	12 bits per color	4.2	20-2000%	19.7” x 17.7”
S3700	Drum PMT	10,000 ppi	12 bits per color	4.2	20-2000%	17.7” x 20”
S3900	Drum PMT	18,540 ppi	12 bits per color	4.2	20-3000%	20” x 25.6”

*To 1000% for repro quality

Sharpening is another interesting difference between PMTs and CCDs. It is possible for a PMT scanner to have an additional PMT solely for unsharp masking. With CCD scanners, sharpening must be handled separately. For some scanners this may take place during post-processing of the scanned file in an image manipulation software program. For others it may occur as part of the production process (as is the case with Color Pilot™/LinoColor™).

Resolution

To compare PMTs and CCDs it helps to understand the following concepts concerning resolution.[4] Scanner resolution can be divided into two categories: spatial and tonal.

- How finely a scanner ‘sees’ is a function of **spatial resolution**. Spatial resolution describes the number of samples that the scanner records in an inch. This is usually described in pixels per inch or dots per inch. This has an effect on the amount of fine detail that is recorded in an image.

  To use TOPAZ as an example, the maximum spatial resolution is 8,000 ppi (pixels per inch) and the tonal resolution (or bit depth) is 16 bits per color (or 48 bit if you prefer, 16 bits each for R, G, and B). The spatial resolution of TOPAZ brings up another important point about CCD scanners. The CCD line in TOPAZ contains 6,000 elements. To be able to achieve a maximum resolution of 8,000 ppi, a process called interpolation is used to increase the spatial resolution of a scanned file.[5] Because interpolation is fairly commonly used in CCD scanners, the spatial resolutions of different scanners are sometimes difficult to compare. For example, an interpolated scan of 1,000 ppi will never exactly match the quality of a scan with a true resolution of 1,000 ppi. And yet, the difference may be noticeable to only the most discerning of viewers.

  In general, there are good reasons to distrust spatial resolution numbers. The level of detail that a scan is able to resolve depends not only on the spatial resolution, but also on the quality of the scanner’s optical system. If the scanner does not focus properly on the original, then the resulting scan will be of poor quality whether it contains 10 or 1,000 ppi.

  Maximum enlargement size is tied to spatial resolution. In general, scans that are overenlarged begin to display pixelization.[6] (See ‘scaling range’ in the chart at the top of this page.)

- **Tonal resolution** refers to the amount of color or gray information that the scanner captures for each sample. This is usually described in bits per pixel or bits per sample. This only determines how much information is grabbed per pixel, and decides how the range from white to black is divided up. (The extent of the range from black to white is a function of density range. See below.)

  To use TOPAZ as an example, the tonal resolution (or bit depth) is 16 bits per color. Today, most desktop publishing programs work with only 8 bits

[4] For background information on scanning halftones, please refer to the Linotype-Hell technical information piece entitled *Scanned File Size* which appears in the 1992 notebook.

[5] One benefit of the AutoFocus feature of TOPAZ is that less interpolation needs to be done with scans from TOPAZ than from comparable CCD scanners.

[6] For more information on pixelization, please refer to the Linotype-Hell technical information piece entitled *Scan Resolution and Sharpening* which appears on page 43 of the 1994 notebook.

per color and many desktop scanners supply the same 8 bits. Scanners that supply more than 8 bits per color must also be able to somehow distill the more complex 16 bit information into a usable 8 bit form. Even so, capturing the data as 16 bits per color provides greater flexibility for color correction, sharpening, and color quality. On TOPAZ, signal correction, unsharp masking, and scaling are done before the 16 to 8 bit conversion, yielding better sampling for these functions.

It is always important to capture as much information as possible in the scan, even if some of that information is thrown away later. No amount of post-processing work can recover lost detail or produce colors that are truer to the original than what exists in the scan.

You will notice that the PMT scanners in the chart on the previous page capture only 12 bits per color. This provides a good example of why a point to point specification comparison is not always useful. The PMT scanners are able to do as much or more with 12 bits per color than CCD scanners can do with 16 bits per color.

Finally, capturing detail is not solely the function of spatial resolution. Detail that is distinguishable only by differences between subtle shades of color will be lost if the scanner's tonal resolution is not sufficient to distinguish between two very similar colors.

Density range

Density range is another important concept in understanding CCDs and PMTs. The range of densities that a scanner can 'see', is commonly referred to as density range or dynamic range. The range of densities that exist in a photograph, is usually called either density range, tonal range, and sometimes even dynamic range.[7]

The density range of an original photograph or transparency will vary depending on the photographic material and processing, the conditions during the taking of the photograph, and the subject of the photograph itself. Photographic transparencies have a larger density range than photographs on paper. (The blackest black on a transparency may be 3.0 or higher, while the blackest black in a photograph on paper is usually not much more than 2.0.) Even printed pieces have a density range. For example, one of the reasons that printed pieces look better on higher quality paper is that the density range is longer. If you look at the darkest black on newsprint, you will see that it is not nearly as dark as a black on a coated magazine stock. In the same way, the white of newsprint is often fairly gray or even yellow. All of this combines to compress the density range of anything printed on newsprint.

The density range of a scanner is the difference in density between the two lightest colors that the scanner can distinguish, and the two darkest colors it can distinguish. Scanner density ranges usually fall between 3.0 and 4.2.

If the specification sheet of a scanner says that the density range is 3.0, that means that the range between the two lowest and the two highest densities that it can tell apart is equal to 3.0. For example, if the lowest density is .1, then the highest would be 3.1. If your original images consistently had dark detail value above 3.1, then the scanner would not be able to resolve it.

With scanners, the importance of density range can be distilled down to these questions:

- Can the scanner tell the difference between two very light colors?
- Can the scanner tell the difference between two very dark colors?
- At what point is the scanner no longer able to tell the difference?
- Are visual artifacts (so-called noise) apparent anywhere in the density range (particularly at either the high or low end)?

[7] The terms dynamic range and density range are often used interchangeably, both being used to describe the range from white to black on a photograph or printed piece, as well as the range of colors that the scanner can distinguish. In this article the term 'density range' will be used to describe both of these concepts.

The specification sheet for TOPAZ lists TOPAZ's density range as 3.7, with a maximum resolvable density of 4.0. The optical system in TOPAZ is an important consideration because it is optimized to avoid noise in the highlight and shadow areas of an image. Lower quality CCDs are often subject to this type of noise. And so, simply to claim a large density range is not enough if that density range is marred by noise. (This noise is one reason why CCD scanners must capture more bits of tonal resolution than PMT scanners.)

Comparing specifications

Any numbers listed in scanner specification sheets should be closely examined for discrepancies. It is not unusual for manufacturers to include inflated claims in their specification sheets. This is partly because some specifications are not easily characterized by a single number (resolution for example). In addition, there may not be agreed upon methods for measuring and verifying specifications for things like density range. (Sometimes a theoretically calculated density range will be included in the specification rather than a density range that has actually been measured.) Finally, because of differences in the technologies, it may not be fair to compare certain specifications on an 'apples to apples' basis. (Tonal resolution is a good example of this.)

Conclusion

Can CCD scanners produce the same quality scans as PMT scanners? They certainly can. In fact, a well-designed CCD scanner can actually surpass the quality of a poorly-designed PMT scanner. In general, the quality gap between CCDs and PMTs has narrowed significantly. For many viewers the difference will be indistinguishable. For others, advantages in format capabilities, density range and productivity will play a more important role in the choice of a scanner. In each case, it is an individual decision based on the types of images, the kinds of originals, enlargements, and quality expectations. For many, the most important difference relates to resolution and enlargement size. Quality differences therefore are more likely to be noticed in images that are significantly enlarged.

A quality scan depends on a number of factors, it is not only affected by the type of scanner (PMT or CCD) but also by unsharp masking, color correction, and the conversion into CMYK. These factors, as well as the scanner's construction, optics, and mechanics, all play a role in the production of a quality scan.

Acknowledgements

Many thanks to Steve Beneduci, Georg Hollenbach, Phil Hunt, Frank Kupke, and Jimmy Yellen of Linotype-Hell for their help in producing this document.

Please direct any questions or comments to: Jim Hamilton, Marketing Department, Linotype-Hell Company, 425 Oser Avenue, Hauppauge, NY 11788
(For subscription information on the Linotype-Hell technical information series, please call 1-800-842-9721.)

December 1994, Part Number 7045