Reflection Microdensitometry in the Digital Age

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Abstract

This paper reviews the issues pertaining to reflection microdensitometry studies of printed media, with particular emphasis on inkjet printing.

Traditionally densitometry on a micro scale was achieved using a device called a microdensitometer. The predominant use of such equipment was for transmission studies of images recorded on photographic film. With the advent of inkjet technology, where the majority of media are opaque diffuse reflectors any need to analyze images on a micro scale will need reflection facilities. This paper details the design parameters that need consideration for reflection densitometry on a micro scale. Comparisons with flatbed scanners and camera based image analysis systems are also covered. The measurement issues are also pertinent to Digital Fabrication systems too!

Introduction

Traditionally densitometry on a micro scale was achieved using a device called a microdensitometer, an example of which is shown in Figure 1.

Figure 1 A Perkin Elmer PDS 1010A microdensitometer

Microdensitometers were typically used to analyze image structure and to make measurements of Modulation Transfer Function (MTF), image noise and granularity. The vast majority of microdensitometry literature covers transmission microdensitometry for photographic film products. As an example a compendium of work on microdensitometry written in 1995 contained 58 papers[1]. Only 1 of these covered reflection microdensitometry[2] and given that it was presented in 1976 covers the topic of scanning photographic papers. However, one excellent review paper appeared subsequently[3].

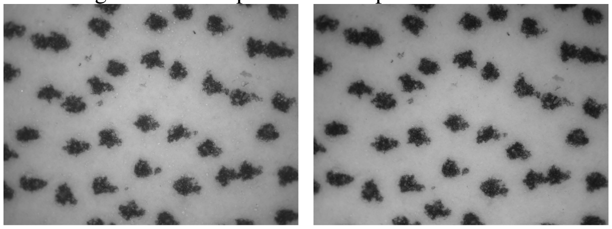
Some commercial microdensitometers had reflection optics available as an optional extra. These were similar optical systems to those made available for reflection microscopy. The options of light and dark field illumination and numerical aperture combined with independent illumination and collection aperture settings make potent combinations for the analysis of reflection images.

This paper uses photo microscopy to illustrate the effect of some of the variables that can be used to investigate the image physics of digital prints. These methods can also be used to quantify structural parameters in Digital Fabrication too[4].

Illumination optics for reflection microdensitometry

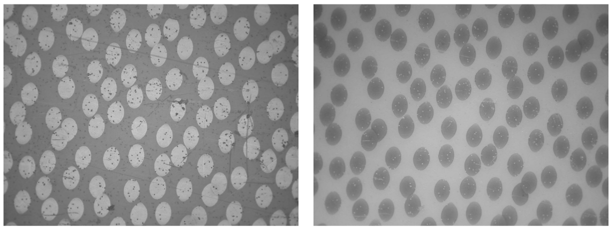
It is beyond the scope of this paper to explain the optics of the microdensitometer. This is covered elsewhere in substantial detail[5] with particular emphasis on the transmission case. However, the illumination systems needed for reflection work are considered here.

It is commonly known that surface reflections from glossy media can substantially reduce measured density, particularly at high diffuse densities[6]. As a result bright and dark field densitometry can give substantially different results. However, there is another effect to be considered in this case – the differential gloss between printed and unprinted media[7].



Bright Field Dark Field

Dye based ink on bond paper



Bright Field Dark Field

Pigmented ink on porous media

Figure 2 The effect of illumination geometry on dye and pigmented inkjet inks

Figure 2 shows a good example of the difference bright and dark field illumination can make to some inkjet images. With diffuse images exhibiting little or no gloss difference between printed and unprinted areas the choice of light or dark field makes little difference. This is illustrated here by dye ink spots on a bond paper. However, with inks exhibiting greater gloss differential the effects are much more pronounced, illustrated here for a commercial pigmented black ink on porous glossy media.

The effect of Numerical Aperture

It has been shown that for diffusely reflective media such as photo or inkjet papers the measured densities are a function of efflux numerical aperture[6]. This is because the solid angle over which the light is collected changes with numerical aperture resulting in a different percentage of diffusely reflected light being collected. If the sample is a perfect diffuser it reflects light equally at all angles. A high numerical aperture will therefore be a more efficient collector of light from such a sample.

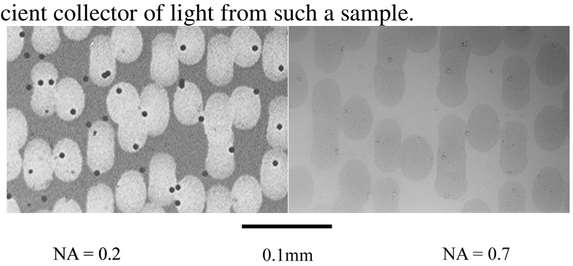


Figure 3 The effect of Numerical Aperture on pigmented ink / media dots

On inkjet prints where inks and media have substantially different gloss characteristics the numerical aperture will profoundly influence the contrast of the image, as Figure 3 shows.

One further variable associated with numerical aperture is the issue of resolution. As in classical microscopy, resolution increases with numerical aperture. However, in microdensitometry the size of the scanning slit is a further variable. The effect of slit dimension on resolution is covered in detail elsewhere[5]. Suffice it to say that narrow slit *widths* give increased resolution but larger slit *areas* give greater light throughput, typically increasing signal to noise ratios.

Depth of field and media flatness.

Depth of field is another variable associated with numerical aperture. However, the special issues pertaining to reflection media mean that this warrants separate consideration.

One particular issue when considering inkjet media is the surface flatness. Media such as coated canvas and fine art papers have substantial surface relief. Even much flatter media such as plain and cast coated papers can have significant and different surface roughness on a micro scale[12].

The printed image can in itself exhibit significant surface roughness effects. In aqueous inkjet this can occur when the media is prone to high levels of cockle when printed. It can also be a feature of printing techniques where a significant ink thickness is used, such as in some thermal transfer technologies. This effect can also occur with pigmented inkjet inks on porous ink jet media[8] and is well known in Digital Fabrication[9].

Depth of field may also be an issue where the colorant is not uniformly distributed in the imaging layer. This has been shown to be the case for pigmented[10] and dye images[11]. Figure 4 shows sections through a cyan dye ink spot on porous and polymer media.

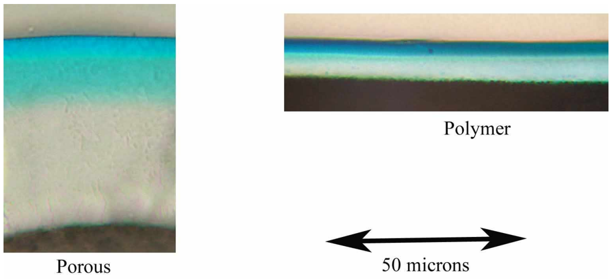


Figure 4 Dye ink sections on porous and polymer media

It can be seen that the depth of penetration of the dye is very much greater in the case of the porous media. Even leaving apart the greatly different optical characteristics of these 2 layers this means that the optics required to image the structures in depth are somewhat different.

Media issues

In general these can be related to the dot gain of the ink/media system employed. There are also special issues related to swellable polymer media.

Mechanical and optical dot gain

Dot gain can be defined as the increase in dot size of the final printed medium over the initial or intended size. It is useful to consider dot gain under two headings – mechanical and optical.

The mechanical dot gain properties of various inkjet ink/media systems can be very different. Mechanical dot gain is caused by the lateral diffusion of ink in the media. One driver of this is the wettability of the media that can be quantified by dynamic contact angle measurements[12]. It is important to consider the issue of printed dot morphology when considering the optical requirements for image analysis[4].

Optical dot gain can be defined as an apparent increase in dot size due to light scattering within the media[13] and as a result there is substantial variation with media type[14]. In addition the effect will also be influenced by the illumination geometry and different illumination and optical systems will give results that are again media dependent.

Swellable polymer media

It has been shown that microdensitometer measurements on swellable type media are a function of illumination area[2]. Because of the contribution of multiple internal reflections, the area to be measured has to be over-illuminated by several hundred μm to achieve results that correlate with typical ambient viewing illumination[3]. Fiber optic ring illuminators achieve this objective admirably. By illuminating evenly at all azimuth angles the effect of surface textures and spatial image structure are also minimized.

It has been noted that images recorded within the gelatin layer on a coated paper appeared less sharp than an ink line directly on paper. This is a result of multiple internal reflections within the gelatin layer from a diffuse surface in optical contact. As a result, microdensitometer slit widths of up to 9μm can be used without affecting the results from an image in a 10μm thick gelatin layer[15]. However, it should be noted that a slit width of 9μm still gives an effective resolution of 2800 dpi! These results suggest that scans made at around 1000 dpi may in some cases underestimate the true MTF of a polymer coated product[16].

These internal reflections also cause a decrease in sharpness with decreasing density[15]. This can be attributed to the attenuation of multiple internal reflections within the gelatin layer[17]. These internal reflections have the effect of reducing sharpness. As they are attenuated by increased optical density sharpness increases with density.

Swellable polymer layers require substantial over-illumination to produce a result indicative of real-world viewing so a scanner based or microdensitometer ring-illumination system is appropriate. However, in cases requiring analytic investigation of printed image structure more localized illumination geometry would be more appropriate.

Comparison with other optical systems

There are alternative devices for image acquisition to determine image quality metrics. A comparison of the attributes of these compared to the microdensitometer is given below. For high precision work the microdensitometer is still the instrument of choice. This is particularly true for edge analysis (and therefore many MTF studies) where spatial image processing issues can be a particular problem.

Flat bed scanners

Flat bed (desktop) scanners are an obvious alternative to reflection microdensitometers for image analysis. They have found application for use on images with low contrast detail such as continuous wedges[18] and other low-resolution applications[19]. They may also prove to be adequate for image noise measurements[12].

However, whilst flat bed scanners are undoubtedly more convenient to use than microdensitometers (and cheaper too!) they have a number of limitations in comparison. The list given below is for reflection systems – a similar treatment has been published for the transmission case[20].

1. Illumination geometry. Flat bed scanners have fixed linear illumination geometry, supplying light at an oblique angle and reading normally. This limits some of the imaging options outlined above.
2. Mechanical and optical precision. A major disadvantage with flatbed scanners pertains to their low geometric precision and lens distortion[21]. The geometric accuracy and optical quality of microdensitometers tends to be much greater than desktop scanners.
3. Image processing artifacts. In order to reduce cost in consumer digital cameras and desktop scanners the detector elements are often a matrix of RGB filtered detector elements. These have a number of issues. Both are prone to spatial processing either in the hardware or software that introduce artifacts into the results[22]. In addition, the file format used to store the image can in itself introduce artifacts due to image compression and encoding[23].
4. Spatial accuracy. Whilst the capability of high-end scanners has been shown[24] to be adequate for most applications, finer detail may require the higher accuracy of a microdensitometer positioning system.
5. Spatial resolution and uniformity. A 1200dpi scanner has a pixel size of around 20 microns. This is rather courser than the resolution found to be necessary to image edges on gelatin reflective media[15]. High-resolution scan settings result in increased scan times which in turn can reduce uniformity because of drift in the illumination and detector systems[25].
6. Reproducibility and uniformity. The lack of repeatability, accuracy and uniformity is an issue when using flatbed scanners for uniformity studies[26]. There is a particular issue around low spatial frequency variation caused by non-uniform illumination[27]. The optical configuration of a microdensitometer is designed to minimize such problems.
7. Image contrast. High contrast images produce flare in optical systems. The capability of even high-end scanners to cope with this is limited and flatbed scanners also have significant adjacency effects that can extend over several mm[24]. Whilst flare is known to be an issue in reflection microdensitometry too the extended optical paths enable stops and apertures to be used to minimize this effect[3].
8. Photometric linearity and gloss issues. High-end scanners run to a limit of around an optical density difference of 2 before scanner flare imposes a practical limit[24]. Desktop scanners have been shown to have problems coping with some of the dynamic range and differential gloss issues of printed media[28]. This suggests that flat bed scanners may have some difficulties with media / ink combinations exhibiting substantial differential gloss, such as pigmented ink images in Figure 2 and the high optical densities that can be achieved on photo grade inkjet media.
9. Detector noise. Scanners have been shown to have a spatial noise power spectrum that is weighted heavily to low spatial frequencies[22]. These spatial frequencies, shown to be <0.3 line pairs / mm are believed to be caused by large-area non-uniformity of scanner response[24].

Microscopes with digital cameras

Whilst not as convenient as desktop scanners this configuration does offer some advantages. In particular the optics tend to be of much higher quality, allowing access to all the illumination facilities described above. Indeed, in terms of convenience this configuration can be superior to microdensitometers. The only optical facilities normally missing are the field and scanning slits[5].

Microscopes can also have similar scanning capabilities to microdensitometers, as some are equipped with motorised scanning stages. However, they are unlikely to have the extended scanning dimensions of a microdensitometer such as that illustrated in Figure 1, which can scan a 20 x 25cm sample with ease.

It is with the digital camera that the most important issues arise. In consumer digital cameras the image is collected on a sensor where each pixel is sensitive to only one colour. The remaining light is absorbed by a filter mosaic resembling a 3-color chessboard. A typical consumer camera relies on processing and filtration to fill in the data from the “missing” pixels leading to loss of resolution and image artifacts[29].

Conclusions

Microdensitometry has many attributes that make it useful for the analysis of the image science of printed reflection media. Examples given in this paper show the application to inkjet printed media. Although flatbed scanners are a more convenient tool their optical characteristics are not as versatile or as accurate as a microdensitometer.

As we move into the era of Digital Fabrication the accuracy and the versatility of the reflection microdensitometer may again be of value.

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Author Biography

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