Photo Printing by Dye Thermal and Inkjet Techniques – Status and Prospects

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Abstract

Recent progress in inkjet printing has increased quality to near photographic levels so that it is now comparable with that achieved from thermal dye transfer. This Paper compares the technologies, especially with regard to print speed, durability and the versatility of the printing system.

At present, there appears to be a need for both inkjet and D2T2, because of the significant differences in performance and end use.

Introduction

Ten years ago, thermal dye transfer (also known as D2T2 or – erroneously – as dye sublimation transfer) was widely available and producing photographic quality images. At that time, very few desktop inkjet printers had color capabilities, and image reproduction was primitive. Very few people would then have guessed the enormous advances that have since been made in photo-quality inkjet printing following Hewlett-Packard's announcement[1] of their intentions five years ago.

The best of today's inkjet prints and dye thermal prints provide stunning quality. In a 3-way comparison with photographic prints, one can score points for each of the technologies, but this paper is starting from the assumption that the image quality of the best examples is sufficient for almost all purposes. The comparison will be around all the other factors that influence the choice of printing technology, such as print speed, image durability, ease of use, versatility and cost.

The driving force for these changes and for the reductions in the cost of printers has been the opportunity provided by the advent of digital photography. We are only just beginning to see the extent to which this is affecting the way that we all generate and look at pictures.

Discussion

Print Speed

D2T2 printers have always had a speed advantage over inkjet. For example, when we compared the printing of a best-quality A4 image from five different inkjet printers in 1997, the print time was between 8 and 14 minutes, which compared with the print time of 3 minutes for a D2T2 printer of the same vintage.

Inkjet print speeds have increased since then, and are at least partly dependent on the media. There are two fundamental divisions of media, porous and non-porous. Porous media can absorb the ink very quickly, and do not place a practical limit on the speed of printing, while non-porous media have a continuous polymer coating that severely limits the speed of ink absorption. This is because the ink is absorbed into the polymer by a swelling process, and the rate limited by the rate of diffusion. It is likely that this will always be a limiting factor for this type of media construction, as diffusion is well known to be a slow process.

The obvious reason for desiring fast ink absorption is in order to ensure that the print can be handled as soon as it leaves the printer. It is perhaps more fundamental to ensure the arriving drops are kept under control and that they do not have a chance to spread or coalesce and thereby degrade the image quality. The issue arises because each pixel of the printed image is built up from an assembly of different dots of ink. The individual drops may be of different volumes, and some may be of low concentration "photo" ink, which gives very good control over the color, but inevitably means that a larger volume of liquid must be handled by the media. If a second drop of ink, either of the same or a different color overlaps a drop that has not yet been absorbed, then the drops will coalesce, and reduce the quality of the image. This means that the rate of arrival of the ink drops has to be limited in order to maintain image quality.

In order to make full use of the capabilities of today's inkjet printers, it is necessary to use the faster ink absorption provided by porous receivers, which are orders of magnitude faster than swelling-type receivers. Capillary action provides the driving force, and is fundamentally a very fast process. Instead of being the limitation on print speed, porous receivers are capable of absorbing the ink faster than today's printers can deliver it; they therefore provide a route forward to further development of inkjet technology.

It is relatively straightforward to produce a porous matte surface by coating with a particulate filler held together with insufficient polymer to fill the gaps between the particles. It is much more difficult to produce a porous *glossy* surface. This, however, has been achieved using *micro*porous structures, where the pores are significantly smaller than the wavelength of light, in order to minimize the effect on reflection from the front surface (and hence the gloss) and light scattering (and hence obscuration of the color). In order to achieve high gloss and avoid distortion of the image, it is also essential to avoid cracking in the receiver layer. This is probably the single most difficult technical issue that has to be solved in making these receivers.

When printing onto microporous paper of this kind, the limiting factor is now the printer. It is possible to obtain a high-quality A4 image in around 3 minutes. Of course D2T2 printers have also continued to develop. At present, a print time of about 30 s is standard for an A5 print, and 90 s for an A4 print. The speed record is probably held by a new A6 printer that delivers a finished print in 10 s. An equivalent A4 printer would take 20 s.

A contribution to the time taken for printing comes from the need to process the image data. An inkjet image normally requires a complex computation before the data is sent to the printer, because each pixel of the printed image is made up of a number of dots of each color. These dots may be selected from a range of drop sizes, or from full-strength or dilute ink. On the other hand, D2T2 printers usually carry out the computation internally, and require only the image data to be input. This extra computational power naturally adds to the cost of a D2T2 printer, but is becoming less significant as time goes on.

Additional intelligence in inkjet printers would probably bring speed benefits, but would need to be flexible in order not to limit the usability of a range of media.

Image Durability

The image in a D2T2 print consists of dye molecules that have been transferred into the surface of the receiver medium. It has been found that prints can be stored for decades without significant color loss or damage, provided that they are kept out of light and are not subjected to attack by finger-grease, plasticisers or other chemical agents. Light-fastness is, of course, a common problem of any color printing technology, but susceptibility to plasticisers is a particular issue for D2T2 because the dyes used are normally soluble in plasticisers, which are commonly used in certain types of plastic wallet.

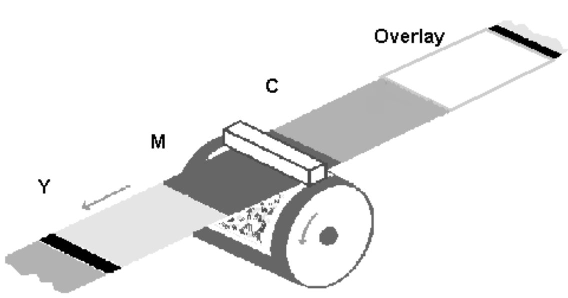

Figure 1. "Fourth Panel" protection of D2T2 prints

There are two ways in which these issues have been tackled. The most common approach is to use a protective layer, which is applied in the printer as an extension of the normal printing sequence. After the three color panels (YMC) have been printed, a fourth panel, which consists of a layer of polymer, usually containing a UV absorber, is applied[2,3] as an overlay (See Figure 1). The polymer mass-transfers onto the image and provides protection against mechanical damage, finger grease, plasticisers and light.

The second technique has been developed by Konica, who have shown[4] that chelation chemistry can be used to provide prints of exceptional stability. The light-fastness and stability to plasticisers are both excellent, as is the gamut of colors that can be reproduced. The prints are perhaps less mechanically robust than those with a protective fourth panel, because there is no physical barrier in the way of abrasion. However, there is still the option of providing fourth-panel protection on top of the photochelate chemistry.

There have been some well-documented issues with the light fastness of inkjet prints, particularly where dilute "photo" inks are used[5]. Because of this, there is significant interest in the use of pigmented inks as a light-fast alternative to the more usual dye-based inks. This is continuing to provoke a great deal of discussion. Our own view is that the undoubted benefits in terms of light fastness are to some extent offset by the smaller color gamut. It also appears to be more difficult to design glossy media for use with pigmented inks.

Although swelling media print much slower than microporous media, in general they have much better light-fastness [unless they contain sensitizing materials such as poly(N-vinylpyrrolidone)]. Some major advances have recently been made in the light fastness performance of microporous media, which formerly had very poor stability. Although the light fastness has been improved (see the results below) there is still a concern that the prints might fade when exposed to ozone or other atmospheric contaminants. An early attempt at light-fast media was withdrawn because of this surprising sensitivity.[6] Early indications are that the more recent media have much better durability, but until these issues are fully resolved, it is a good idea to display all prints behind a layer of glass, which greatly increases their lifetime.

Another problem with light fastness testing is that it almost invariably involves some form of acceleration using a high-intensity source. The normal assumption is that there will be reciprocity in the behavior of the materials – i.e. that a doubling of intensity should lead to a doubling of fade rate. Unfortunately, this seems to be a considerable oversimplification for some inkjet materials[7], although we have never seen evidence for serious deviation in D2T2 media.

We have measured the light fastness of some prints in an Atlas Ci35 at 60ºC (black panel) and 50% R.H. at a light intensity of 1.5 W m^{-2} at 420 nm. Comparisons need to be made with care, as some of the prints on test are believed to be the best available from the technology, whereas others are more representative of the general level. No attempt was made to determine the effect of ozone or other active gases.

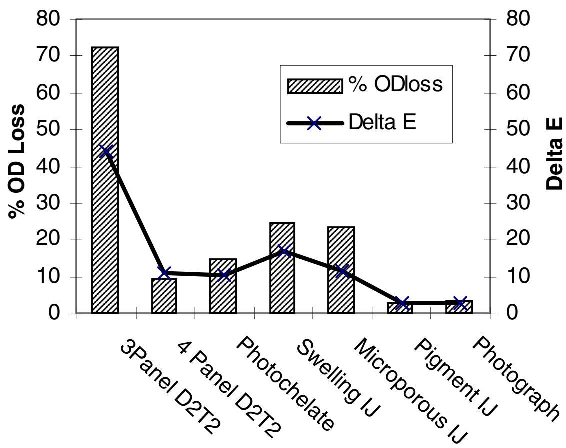

Figure 2. Light fastness data for examples of different printing technologies (72 hour exposure).

Unlike D2T2 images, inkjet prints are not in general susceptible to attack by plasticisers, but instead are vulnerable to water. Given that the dyes are delivered from the printer to the media surface as a solution in water, it is perhaps surprising that inkjet prints show any stability at all to water splashes. However, the best microporous and swelling media will allow the prints to be submerged in water with no running of the dye. This apparent magic is performed by having a large surface area available for adsorption, by controlling[8] the pH, and by the use of cationic "mordants" to fix the dye electrostatically.

Mechanical robustness of inkjet prints is still an issue. Swelling media tend to have a relatively soft surface, especially under high humidity conditions. This is usually very flexible, but susceptible to scratch damage. The surface of microporous media is much harder, but is also more brittle, and can suffer from delamination or cracking if bent round a sharp radius. D2T2 prints tend to be very tough, especially if protected by a fourth panel overlay.

Versatility

Inkjet technology clearly scores over D2T2 in its capability to act as a general printer for personal computers. The ability to print text onto plain paper is something that D2T2 cannot match. Inkjet printers are also able to handle any paper size up to the limit for that particular printer, whereas D2T2 printers are normally limited to a single size.

There is also an enormous selection of weights and finishes of paper for inkjet printers. Although there are some choices available for D2T2, there is nothing to match this.

But this limitation can also give D2T2 a specific advantage. Many passport authorities around the world have given approval for the use of specific D2T2 media for providing the prints to be used in passports. This is because a given set of media defines the nature of the print, right through from the substrate and the image and up to the protective overlay on top. It is much more difficult for inkjet media to be defined in this way, as a given paper might have been printed in any one of a number of different printers, with no indication as to whether the inks in the system have met the regulatory requirements.

There are other areas in which D2T2 provides the most convenient or even the only option. For example, D2T2 can be used to print directly onto PVC "credit" cards to provide personalization and security. This is used widely in many areas from theme parks to banks and drivers licenses.

D2T2 is also very well set up for the retransfer of images. One of the earliest applications was in the production of personalized coffee mugs by using heat to transfer a D2T2 image from a print to a special receptive layer on a mug. This has recently been taken into the third dimension by retransferring a D2T2 image onto a molded surface, such as the back of a mobile phone. Naturally, it is rather more complicated to get a flat print to conform to the surface of a 3-dimensional plastic object, while not distorting either the object or the image, but the results are very satisfactory.

Ease of Use

Early adopters of electronic photography have mainly been computer users, who already have an inkjet printer that is in regular use. The transition to printing images on this printer is therefore entirely natural, even if it might be used to provide the excuse for upgrading to a newer model of printer.

As digital cameras displace silver halide, more and more users are likely to want to print their own pictures without the hassle of an intervening computer. There are already several printers on the market that directly accept camera cards and enable printing of the images – usually with the option to crop or adjust brightness and contrast. At least one printer even provides the ability to store images on a CD. Of course, this technology is a matter of electronics rather than printing; however, many of these new users are likely to be intermittent in their demands on the printer. Anyone who has used inkjet printers knows that they are at their best when called on to perform regularly. If they are put on one side for any length of time, then head-cleaning cycles kick in, and possibly, manual intervention is needed to clear blocked jets.

D2T2 printers, on the other hand, can be neglected for long periods of time and still produce a perfect print when switched on. This is likely to be a major convenience factor, at least for a proportion of users. They are also usually more portable, without the concerns of transporting liquid ink, although they are not well suited to mobile operation because of the relatively high power requirements of the thermal head.

The wide choice of inkjet media can sometimes be daunting, and the results obtained from unsuitable paper can spoil people's perceptions of the quality of output available from a printer.

Cost

At first sight, the cost of D2T2 media seems much higher than that of inkjet. However, once the cost of the ink is taken into account, the difference shrinks. Printer manufacturers normally quote cartridge lifetime in terms of 5% coverage per color. For most photo printing, that is a major underestimate of actual ink usage. A real picture can easily take many times this amount of ink. When we surveyed a number of inkjet printers in 1998 we obtained real ink costs by repeatedly printing the same image until the cartridge was exhausted and needed replacement. Overall costs are shown below, and it is clear that at that time the ink costs dominated the total cost of the print. Figure 3 shows the data obtained at that time for printers A to E, and a wide range of £0.78 to £2.14 for the cost of a typical A4 print.

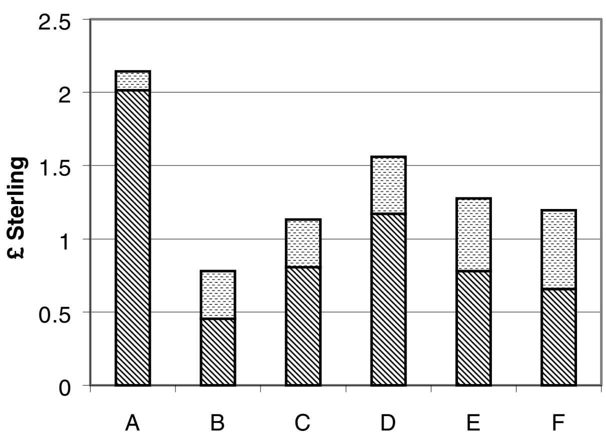

Figure 3: Costs of an A4 print for different printers: dotted line = paper, diagonal stripe = ink.

The current situation has changed little: calculations based on a similar study[9] of a modern printer yield column F, which is well within the range of the earlier values.. Those who look at the real cost of running their inkjet printers will not be surprised that the cost of the ink outstrips the cost of the paper, especially with photo printers using dilute inks. It emphasizes once again that it is false economy to sacrifice image quality by skimping on the media. D2T2 is currently at the top end of the price range, especially in Europe, at a cost of £2.10 per A4 sheet.

As commodity items, inkjet printers are now priced very competitively, but it is only in the last couple of years that D2T2 printers have begun to see something like the same economies of scale. It seems probable that this process will continue, as digital photography provides the long-awaited "killer-app" for D2T2.

Conclusion

D2T2 and inkjet printing can both provide near-photo-quality prints, but offer a significantly different set of properties. The permanence of images printed with pigment inkjet inks promises to be similar to that of the best silver halide prints, but at the expense of a reduction in color gamut and some other limitations. D2T2 prints offer the next best permanence.

Inkjet printers are a natural choice for multi-purpose printers to be run off a PC or Mac. They are less well suited as dedicated printers and for occasional use. D2T2 prints are more versatile in their further application, such as retransfer.

Both technologies are likely to thrive in the era of digital photography.

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Biography

Richard Hann graduated in chemistry from the University of Oxford, England in 1967. After a Ph.D. at Sussex, England and postdoctoral work at UBC (Canada) and Exeter (England) he joined ICI. He has worked on imaging media since 1984 as part of ICI Imagedata, and is the Principal Scientist. He is author of more than 50 papers and 35 US patents, and is a member of the IS&T and the Royal Society of Chemistry.

Andrew Clifton graduated in 1990 with a BSc. degree in Pure Chemistry from the City University in London England), followed by a Ph.D. on polymer surface modification at the University of Bath (England). In 1994, he was awarded, by the European Community, a PDF at the Institute of Microtechnology (IMM) in Mainz (Germany) on polymers in deep lithography. Since 1995 he has been working for ICI Imagedata, researching the fundamental applied property links in imaging media.