

Home Photographic Printing with Inkjet Technology

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Abstract

Desktop color inkjet printing has evolved over the last 15 years. Inkjet color printing began with low resolution 8 color per pixel systems. Simple graphics and colored text printing drove printer development for a long time. With improvements in ink, paper and halftoning, and increased printer resolution, image printing was enabled. Recently, multi-level and high resolution color inkjet printing has begun to emerge. Further developments in ink and media have enabled inkjet printers to print images that can not be distinguished from silver halide photographs. This paper will discuss this current group of new products: how they achieve photographic image quality and how they are changing consumer photography.

Introduction

In 1996 and 1997, a number of products were introduced to the market which launched a new category called PC Photography. These products include digital cameras, photo scanners, and photo printers. Digital cameras provide an easy way to take digital snapshots. Low cost print, slide and negative scanners, along with the included photo manipulation software, provide ways of capturing/digitizing the contents of our photo albums and photo storage boxes. And finally, affordable photo printers produce prints comparable to silver halide photos. This paper will discuss how inkjet printing has evolved to achieve photo quality, some of the key breakthroughs which have enabled photo quality in inkjet printing, and the state of PC/digital photography today and its impact on consumer photography.

Inkjet Printing Evolution

Below are some of the key milestones in inkjet printing which have lead to photographic printing. The technology from both HP and non-HP printers will be mentioned, while focusing on advances that span across the various manufacturers.

The first low cost desktop inkjet printers came to market about 15 years ago. These were low quality, low resolution (90 dpi) black and white devices devoted to text printing. They typically used disposable ink cartridges. Acceptance was limited by problems with ink nozzle reliability, and low quality printing. As the technology stabilized and went into higher volume manufacturing, the quality and reliability greatly improved.

The jump to 180 dpi color provided both increased resolution and the first desktop color inkjet printer. This class of color inkjet printers were used for text and business graphics printing. While they were capable of printing images, the quality was poor.

Continued advances in inkjet cartridge and nozzle technology brought 300 dpi black text printers, followed by 300 dpi color. These produced incremental improvements in printing images, but were still far from photo quality.

Coated inkjet medias gave brighter, more vibrant looking output with this class of printers, although the dots were obviously visible and objectionable in images.

An increased focus on improving halftoning and color matching algorithms brought better image quality without changing fundamental printer characteristics. Color error diffusion methods added quality over dither cell methods. Color matching methods began to give reasonable approximations of what users saw on their CRT screens.

Without increasing spatial dot resolution, multi-drop printers improved quality by printing multiple levels of colorant on the same pixel location. Again an incremental improvement was achieved in image printing. Further halftoning gains improved both image quality and throughput.

Increases in resolution for binary color printers brought capabilities of 360 and 720 dpi color. These printers relied on special low dot gain papers to pack information at a higher density. The quality of these prints was excellent on special low dot gain media. However, on plain paper, these printers had to lower their dpi settings due to ink bleed issues.

In 1996 and 1997, the current group of color inkjet photo printers was introduced. They utilize more than the traditional CMYK inks. These new printers use 6 or more inks, adding a low concentration cyan and magenta ink, and sometimes a light yellow. These printers use the light inks to produce subtle highlights and smooth, grain free images. Some of these devices produce prints which consumers judge to be as good as or better than traditional silver halide prints.

This class of multiple concentration ink printers currently includes the Hewlett-Packard PhotoSmart Photo

Printer, the Epson Stylus Photo printer, and the Canon 700 Photo printer.

Inkjet Photo Printer Technology

What constitutes photo quality in the eyes of the consumer?

For the last few years, printer manufacturers have claimed that their inkjet printers have "Photo Quality". In reality, these printers were able to print images that were remarkably good for computer print outs. When judged against the previous generation of color inkjet printers, the improvement in image quality was remarkable. Less dot structure and halftoning patterns were visible. Dots were smaller, and colors better. No one would, however, confuse them with the original photograph! When judged against the original, there would still be a significant amount of grain and dot structure visible. The current class of 6 ink photo printers all claim "true" photographic quality.

What does it mean to achieve photographic quality? How do you measure it? In the R&D lab, we can define and measure photo quality by measuring product attributes such as tone reproduction, grain, gloss, paper thickness, image sharpness, and color accuracy. But more importantly, how do consumers define photographic quality?

In this new market category, the answer can be found best by talking with customers. Most people are consumers of photographs and film. They have preferences and opinions about photo quality as it relates to their own and other pho-tographs. By talking to customers we can understand their needs and expectations, and use their impact to drive our tradeoff decisions. Consumers see the attributes listed above, but use a different language to describe them. They talk about picture clarity, evenness of color, vibrancy of color, "correct skin tones" and realness of colors. By learning the language of the consumer, we are able to translate consumer terms such as "image clarity" into dot structure or graininess. Scientists and engineers sometimes have different perceptions of what is important in photo quality compared to consumers. By having engineers sit down with consumers to discuss sample photographs, a better understanding of consumer photography needs is achieved.

An excellent test for consumer photo quality is the following: When viewed by the target customer, can the customer tell the difference between the silver halide print and the inkjet print? Does he/she see printer related artifacts such as grain or banding? Does the consumer think the quality meets or exceeds the silver halide print? Does the consumer prefer the inkjet print the majority of the time? Through this research, it has been discovered that if the consumer prefers the inkjet photo the majority of the time, then true photo quality is achieved.

How do inkjet photo printers work?

In previous non-photographic color inkjet printers, 8 colors choices were provided per pixel location (Red, Yellow, Green, Cyan, Blue, Magenta, Black and White). This method is sometimes referred to as binary color printing. Each colorant (CMYK) is either on or off per pixel. To print images, halftoning is applied to the image data to produce a printable image containing pixels of the 8 color set. In order to simulate a color other than the 8 basic colors, the halftoning utilizes multiple pixels over an area. For example, to get a 20% red in an area, the halftoning would produce pixels where 8 of 10 are white and 2 of 10 are red. Skillful distribution of the dots minimizes induced patterns or halftone noise.

At a distance, the eye integrates the white and red pixels into a light red tone. Still, at each pixel, there is a large difference between what was desired (20% red) and what was printed (100% white or 100% red). As the eye is moved closer to the image, visible and often objectionable dot structure and grain become visible.

Photographic inkjet printers rely much less on halftoning to get intermediate color tones. By adding the capability of placing multiple numbers of drops of the same colorant on the same pixel location, and by adding light inks, the printer goes from 8 color choices per pixel to many thousands of colors per pixel. Using the example above, a 6 ink printer trying to print an image area of 20% red might use combinations of 15% and 25% red pixels to get the right color. The difference between the desired color and printed color at each location then becomes so small that the eye does not see the dots at a typical photo viewing distance of 8 to 12 inches.

In binary printers, the goal is to modulate the area of dot coverage to yield intermediate color tones. This method gains significantly with increases in the number of dots placed per inch. The dots become smaller, and the eye is better able to integrate multiple small pixels into inter-mediate color tones.

Six ink printers strive to modulate colorant density instead of area coverage. With these printers, large gains can be made by providing additional useful steps in colorant density choices per pixel.

How much resolution is needed or alternately, how many usable levels of colorant per pixel are required to print photos? There is a theoretical answer, but it is based on a lot of assumptions that break down in real products. So, practically speaking, the answer depends on a number of attributes of the product including dot gain, dot shape, dot positioning accuracy, visual spacing between levels of colorant, contrast between the paper and ink drop, capability of the paper to accept large amounts of ink.

One way to assess the tradeoffs between dots per inch and number of color levels is by comparison with other printers. By doing this, some insight can be gained into practical upper and lower bounds for the number of levels and dpi needed.

A high quality 300 dpi dye sublimation printer typically does not suffer from resolution issues when prin-ting good quality images. These printers typically have 256 levels of each colorant (CMY), effectively giving continuous tone printing. This capability yields more than 16 million color choices per pixel. Going beyond 300 dpi for these printers yields very little practical increase image quality, but adds substantial product cost and computation time.

Binary printers could also produce near continuous tone printing. Simulations of 2400 dpi binary color printers show this.

Alternately, the PhotoSmart 6 ink photo printer, at 300 dpi, achieves near continuous tone with less than 40 levels for cyan and magenta, and less than 8 levels for black and yellow. Certainly this printer would benefit from more levels of colorant choices or the same number at a higher resolution. It is estimated that by either doubling the number of effective color levels per pixel, at 300 dpi or having the same number of colorant levels at 600 dpi would move this printer from "near" continuous tone to continuous tone capability.

Technology Breakthroughs

In order to have photographic quality, an inkjet printer must consistently produce prints that look and feel like photographs. A number of attributes of inkjet printers had to be improved upon to make this happen.

Numerous breakthroughs were made with the HP PhotoSmart Photo printer. Some of them also apply to the other two photo printers in this class.

Grain or image clarity - Depending on which paper is selected for printing, the PhotoSmart printer can print between 2 and 8 levels of black and yellow ink, and between about 5 and 40 levels of magenta and cyan. This yields non-visible dot structure for the casual observer. The more critical, trained observer will still notice some slight grain and dot structure in certain areas of some images.

Color gamut - The PhotoSmart system achieves a larger color gamut than silver halide prints. This was designed to support optimization of graphics and clipart which are often printed with photographs. In addition, the system delivers a "black" density of over 2.5 on the PhotoSmart Glossy paper, providing excellent tone range and shadow detail.

Look and feel of the photo paper - HP PhotoSmart Glossy Photographic paper looks and feels like traditional silver halide prints. It has a high level of consistent gloss in both the imaged and non imaged areas. In fact, the paper uses the same photobase paper stock as silver halide prints. A proprietary coating was developed to receive ink, while still mimicking the gloss and appearance of silver halide photos.

Previous glossy photo medias were plastic sheets with a special coating, that in no way resembled photographic paper. They were thin and flimsy, and made a peculiar "Plastic Sheet" sound when handled.

Reduction in banding and printer artifacts - Inkjet prints typically exhibit some periodic printer-induced visual artifacts. This can be due to dot placement error, nozzles not shooting straight, and other causes. Expensive technologies exist for improving the mechanical accuracy of a printer mechanism. The PhotoSmart printer achieves this accuracy within the constraints of a low cost printer mechanism.

To help reduce artifacts caused by printer nozzle defects, technologies have been developed for ordering the dots to be placed on each pixel and to separate out which dots are to be printed on each pass, and by which nozzles. This helps to reduce visually objectionable patterns.

Image Permanence - Image permanence is an important attribute of silver halide photographs that is not normally associated with inkjet prints.

Substantial ink and media advances in the PhotoSmart system have yielded dramatic lightfastness gains. While most desktop inkjet prints available today have noticeable fade after a few months of exposure to indoor home or office light, PhotoSmart prints on glossy paper last over 3 years under the same conditions without substantial change in color.

Throughput - In the PhotoSmart system, a number of advances were made to allow more ink to be deposited on the media over a shorter amount of time. This allows an 8×10 photograph to be printed in normal quality mode on photo glossy paper in 5 minutes or less.

Affect of the Digital Revolution on Consumer Photography

Digital imaging is revolutionizing photography. Professional photo studios are starting to use high resolution digital cameras. Insurance companies are using digital cameras to record auto insurance claims.

Most analysts predict that digital photography will have a large but gradual impact on consumer photography. What is still widely debated, is the rate of adoption of this technology at the consumer level. Who will replace their silver halide photography with digital photography? Who will supplement their silver halide process with digital photography? Who will let the digital revolution pass them by, being content with traditional silver halide photography?

The shift to digital imaging on the consumer level hinges on several factors: system cost, ease of use, perceived value of the systems, and convenience as well as a desire to improve/personalize photos or incorporate then into creative projects. A complete digital PC photography system today would consist of :

A multi-media PC - Average price $2000
A consumer grade digital camera - $350 to $800
A scanner for prints, slides, and negatives - $500
An inkjet photo printer - $500

Not all components are necessary. A useful system could consist of having only one or two of the three photo accessories. The price of PCs is continuing to drop rapidly each year. Analysts expect consumer grade digital cameras will likely remain in the same price range for a while, but quality will improve dramatically for the same price. Inkjet photo printers will continue to drop in price and improve in quality over time.

Following PC technology trends, the price of a photo scanner/printer or camera/printer combination should eventually reach the $500 level or below. When this happens, there will be an explosion in the demand for these products.

As the market for consumer digital photography expands, it will not steal market share away from silver halide photography. In fact, it will add a whole new dimension to photography and will increase the market for silver halide.

Consumer Photography: Convenience and Unmet Needs.

One of the most compelling features of silver halide photography is it's low cost to the consumer. Disposable cameras are readily available for about $7. For less than $10, the pictures can be developed and printed. Point and shoot 35mm cameras range anywhere from $50 to $350 and up. 35mm SLR cameras start at around $200 and up. Film can be purchased almost anywhere for a reasonable price. Film developing is inexpensive and widely available. Consumers think that it's convenient. There are an abundance of locations to have film developed and printed. Film can be taken to the store and dropped off for pickup one or two days later. Or, by paying extra, 1 hour developing can be specified.

However, consumers do have some recurring issues today with traditional photography, such as hassles getting reprints, difficulty in customizing prints, and difficulty getting the color right on some prints.

To do anything other than routine photofinishing requires multiple trips to the store. On the first trip, the film is taken in to be developed. On the second trip, the pictures are picked up. Later, it is decided that additional services like enlargements or reprints are needed and a third trip is needed to take in the negatives for reprints. A fourth trip is needed to pick them up. Because of this hassle, most people limit the number of reprints and enlargements that they get done.

Often times, it is difficult to incorporate pictures into other projects. Making a photograph the correct size for a card or calendar, or cropping or enlarging require extra trips to the photofinisher. To use photos in creative projects, photo reprints must be cut and pasted so as not to destroy the original print.

Normally the color quality of consumer silver halide prints ranges from acceptable to excellent. However, sometimes the algorithms used by the photofinishing equipment to set the color balance and exposure break down and fail to give good prints.

What does PC/Digital Photography have to offer today?

Convenience - prints can be made any time you want.

Choice - print which photos you want, discard or archive the rest.

Control - software allows you to manipulate and fix common problems with photos such as under or over exposure, red eye, color balance problems and contrast. In addition, you can crop, enlarge and reduce the size of your photos as well as make reprints.

Personalized projects - software allows you to incorporate your photos into creative projects such as greeting cards, calendars and school reports.

Digital cameras with an LCD display offer instant feedback. You can immediately check the picture on the display and take another one if it is unsatisfactory. The ability to print it right away further satisfies the desire for instant turn around of photos.

Uses for digital photography will fall into several categories:

- First time prints - These will typically be made from digital cameras, although some users are beginning to have their slides and negatives developed, but not printed, opting to scan them on the PhotoSmart scanner and printed directly on the PhotoSmart printer.
- Reprints - These will come from many sources, including CD-ROMs, scanners, and digital cameras.
- Creative projects - Users can take the digital version of a photo and incorporate it into creative projects such as greeting cards, calendars, newsletters and school reports.
- Personalizing, customizing, improving photos - This category is enabled by the new imaging applications. Among the new capabilities are editing features such as color balance and contrast adjustment, and red eye removal. Formatting changes such as cropping, enlargements, and reductions are easy to do. Changes to the image such as cutting a person out of one image and placing them in another image are possible. Enhancements such as sharpening, and noise and scratch removal are also available.

However, PC photography today is just beginning to meet traditional photo consumer needs. It is not a replacement for traditional silver halide photography. Silver halide is still the most cost effective and highest quality image capture mechanism. It is not possible to duplicate prints at high speeds using home inkjet photo printers. If the consumer's only need is to take pictures and have the photos printed, he may not be satisfied with the time and effort that is involved. On the other hand, if he is interested in the new capabilities of PC photography, he will be likely to invest time in it.

What will PC Photography offer in the future?

Over the next 3 to 5 years, there will be significant technology improvements in PC photography.

Digital cameras that exceed the quality of the best point and shoot cameras of today will be introduced, at similar prices. Today, digital cameras in the $3,000 to $11,000 range are currently demonstrating quality similar to a good point and shoot cameras. Volume increases are expected to drive digital camera prices to $200 to $300 within a few years. Inkjet photo quality printing will continue to improve. "No excuse" photo printers will be available in the sub $300 price category. Scanners will continue to become smaller, and less expensive, while increasing in versatility. Image quality and color fidelity will also improve.

For consumers, the advances will offer increased flexibility and convenience. The user will be able to hook up his/her digital camera to a photo printer or computer, select the photos for printing, and push a button to produce

the prints. Very little interaction and decision making will be required. Additionally, without a trip to the store, the user can produce multiple reprints, enlargements, selectively cropped photos, etc.

For photo hobbyists, the advances will offer a real digital darkroom. The advanced software now on the market is very capable but requires a lot of training to use effectively. With advances in ease of use, this powerful software will make photo manipulation as quick and easy as word processing.

Once image quality improvements level out, what's next for photo printers?

Although initially, there will be real differences in the quality of different photo printers, some of them will not be obvious to the first time customer. As the customer base becomes more educated about photo printers they will begin to make critical comparisons between photo printer products and traditional silver halide photographs. Expectations for excellent quality will rise. Salespeople and customers will become more aware of what to look for when selling and selecting a photo printer. The consumer will be happy with one product until he is shown a comparison with something that is a little better. If that improvement comes at little or no cost, he will want the slightly better product.

With the future second and third generation inkjet photo printers, manufacturers should reach a comparable quality level of photo quality, even to the experts. Dots will not be noticeable and the color renditions will be quite pleasing.

As image quality becomes equal among the various photo printer manufacturers, the key differentiators in the consumer's eyes will be:

- Ease of use - intuitive and simple products
- Cost per copy - low cost of use, good value for the money, eventually less than traditional silver halide prints
- Purchase price - of the printer
- Point of purchase cost of supplies - How much does it cost to get a set of supplies?
- Dry time -How long must you wait after printing before the prints can be handled?
- Versatility - Is the printer a good all around printer?
- Media quality - Does the photo paper look and feel like a traditional photograph?
- Preference color - Can you make the print look better in some way than the original?
- Creative solutions - bundled software that adds real value in the customer's mind, and makes the printer ready to use right out of the box.

Growth in Image Sources

For first time purchasers of inkjet photo printers, there can be some concern about availability of images to print. Digital images will come from a variety of readily available sources. Predominant sources in the next 3 to 5 years will be:

- Personal scans- Silver halide prints, negatives or slides are abundant. They can be scanned in by consumers using low cost personal photo scanners. Silver halide prints will continue to be a source for scanning well into the future.

- Professional scans - Photofinishers will provide film developing and scanning. They can then deliver images on CD-ROM or can upload them to an image server for access over the Internet. This method will become more practical when network bandwidth in and out of the home dramatically increases. Cable modems and fiber optic connections offer hope, but it will take time for the infrastructure to change over to these high speed links.

- Digital cameras - They are a specialized source for PC photography initially. The convenience and instant turn around of images is an important feature. As the quality improves and the price drops, a higher adoption rate is expected. As that happens, a higher percentage of the images printed will come from digital cameras.

- Internet images - Photos published on the Internet will be important as a source for stock photos.

- Stock photo libraries - Collections of digital photos on CD-ROM are currently in wide distribution.

Summary/Conclusions

The digital photography revolution started with the introduction of a wide range of low end digital cameras. In 1997, the digital photography market expanded with the introduction of true photographic quality photo printers such as the HP PhotoSmart printer. A low cost way of scanning prints, slides and negatives was introduced with the Photo-Smart Scanner. Software has become available for photo manipulation which requires very little training and is fun to use. Future evolution of consumer digital cameras, scanners and inkjet photo printers will change consumer photography by supplementing the existing silver halide processes and adding new capabilities of choice, control, convenience and personalization.