Emerging Applications for Inkjet Technology

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Abstract

Digital printing technology, originally developed for office and data processing applications, has moved beyond those in the past decade and is now finding use in virtually every field of printing, and even beyond printing in the usual sense.

Inkjet printing is leading the way into new application areas. In the past, inkjet printing has been used in product marking, carton marking, addressing, and large format printing and plotting, as well as office and home printing. Today, inkjet technology is being applied in textile printing, the printing of packaging (beyond marking and addressing), postal franking, commercial photo processing, the printing of decorative materials, and even "printing" of three-dimensional objects. Tomorrow, we will see inkjet technology applied in even more esoteric fields, such as the printing of microcircuits and flat-panel displays, and in some areas that cannot be called printing at all.

Introduction

The first significant efforts at applying inkjet technology were directed at the development of electrical signal recording devices called oscillographs, but the greater effort and the first commercial success were associated with character printers, developed in the early 1970's for direct mail applications and in the mid-1970's for word processing.

For the next twenty years, most of the emphasis lay on office printing, and later on home printing, with the result that more than two hundred million inkjet printers have been sold worldwide. This success was extended into the plotter market, as inkjet technology eclipsed pen plotting in the late 1980's, and then into large-format color graphics in the mid-1990's.

During this period, inkjet printing also found wide acceptance in industrial applications, including addressing, product marking, wire-coding, case-coding, proofing, and even in the printing of carpets.

In the mid-1990's, inkjet printing could be divided into two sectors: slow, high-quality color printing for the office,

home, and for design and graphics shops; and fast, relatively low quality printing for industrial applications.

From that time, there has been an explosion of new applications for inkjet printing. This has been driven by several factors: First, by the arrival of new printheads that increasingly offer the combination of speed with quality; second, by the widespread knowledge of the technology that came with its arrival in homes and offices around the world; and most recently, by the development of a wide range of inks and other jettable fluids that address a great range of new applications.

"Traditional" Applications

By "traditional" are meant applications that are well established in the commercial marketplace and that have existed for more than five years. These have been widely discussed and published, and they will be covered only briefly here.

The most important of these are desktop printers connected to personal computers. The success of inkjet printers is closely tied to the growth of the personal computer market, especially the home computer market. Most inkjet printers are in homes, where the low purchase price and color capability are compelling. Electrophotographic printers continue to dominate the corporate world.

Large-format printers were originally an outgrowth of desktop inkjet technology, as the integrated ink supply and printhead were a natural replacement for plotter pens. But the ease of adapting these machines to print color graphics soon gave rise to new markets in the printing of posters, banners, signs, photographic enlargements, and many other products. From this base, large-format inkjet printing has grown to include proofing, sampling and short-run printing of textiles, and printing of rigid materials by "flat-bed" models.

Inkjet technology has been applied in industrial settings for as least as long as in the office. Its ability to print variable information at high speeds without having the mechanism contact the printed material has made it ideal for use in manufacturing settings where the need to print on a moving substrate is common. Examples include the printing of mailing addresses in the bindery, the printing of cartons on lines where they are automatically erected and filled, and the date- or lot- coding of beverage cans on a filling line.

Inkjet printing is also applied to tags, tickets, and labels. Examples include apparel care tags, lottery tickets, and address printing on labels. Inkjet printing is also used in point of sale printers and postal franking systems.

Enabling New Applications

Most of the applications discussed above are based on thermal inkjet technology (most desktop and large-format

printers), continuous inkjet technology (most industrial applications), or small arrays of print channels based on piezoelectric technology (some examples in each category).

The printhead designs used in these examples all require trade-offs between speed and quality, due to their relatively small numbers of channels and low firing rates. In addition, most are limited to low-viscosity inks using solvents such as water or alcohols. Further, most of them have a relatively short life, as measured in the volume of ink ejected.

Over the past few years, we have seen the emergence of a new generation of printheads that may truly be called "industrial grade". They offer up to 500 channels, and may be arrayed to gain speed, quality, and up to eight subtractive or custom colors. They also offer various combinations of faster firing rates, tolerance for a wider range of fluids (varying in viscosity and chemistry), higher reliability, greater drop placement accuracy, and longer service life.

Ink manufacturers have followed with a much wider range of inks, based upon various approaches including water- and solvent-based, phase-change, and uv-curable. These use dyes or pigments suited to the application and often contain other application-specific additives. Other "inks" are fluids that are application-specific, such as low-melting solders for electrical connections.

In some cases, coated or treated substrates have been developed as well, though in general, inks are tailored to substrates rather than the reverse.

All this has enabled a wide range of new applications. In addition, aggressive marketing by printhead and ink manufacturers and the appearance of inkjet printers in most homes and offices have sharply increased the range of potential users that are aware of inkjet technology and its capabilities.

New Printing Applications

The increased speed enabled by piezoelectric (piezo) printheads has allowed large-format inkjet printing to satisfy the need for longer print runs than before, opening up applications requiring moderate volumes.

In particular, the field of textile printing seems poised for new growth, moving from sampling (proofing) and very short custom runs to somewhat larger volumes. Already we have seen semi-production devices capable of printing more than 200m^2 per hour in widths exceeding 3m. It is widely expected that a major trade show in the Fall of 2003 will see production textile printers displayed.

While one of the first commercial successes for inkjet printing was a direct mail printer, this was not followed by other successful forays into the graphic arts market until very recently, when an inkjet color digital press (using continuous inkjet technology) was announced. Several hybrid devices, using inkjet printing to add variable information on a conventional press, or to add color on a monochrome electrophotographic printer, have also been demonstrated. At least one manufacturer has targeted on demand printing of books, and there is at least one effort to produce a page-wide array for the graphic arts market. There is an ongoing debate regarding the merits of inkjet printing versus electrophotography in the document and graphic arts markets, which will no doubt be resolved in the marketplace.

The two also compete for the digital printing of packaging and containers, in the flexographic printing environment. Electrophotography has been used in the printing of labels for packaging, but inkjet appears to be more suitable for printing directly on packaging materials. Several systems with uv curable inks for package printing are available, and the flat-bed devices mentioned earlier are also suitable for this application.

Inkjet technology is also being applied to the printing of bottles and cans, the decoration of music and software CD's, and even to the printing of decorative ceramic tiles.

In all of these applications, it is not expected that inkjet printing will displace conventional technology, but that it will add the capability for variable information, customization, and short runs.

While inkjet technology may be seen as a competitor to screen and other conventional printing techniques, it also serves as an enabler: it is used to create digital screen masking devices, allowing direct production of screens from digital files, and direct-to-plate digital platemakers for offset printing. Both take advantage of phase-change inks to produce short-run masters.

One of the most promising opportunities lies in commercial photo processing. All one-hour and central photo labs are moving to digital processing - not merely to accommodate digital cameras, but to capture the benefits of digital enhancement for conventional photos as well. Most of the printing will be on silver-based digital photowriters in the near term, but improved non-impact printing will quickly capture the market. It is likely to be shared by chemically produced- and liquid-toner electrophotography and by inkjet. Already, inkjet-based minilabs have been introduced by several companies.

Still another opportunity lies in the printing of decorative materials such as wall- and floor-coverings. The printing of carpets by air-deflected jets has been practiced for more than thirty years, but more conventional inkjet systems are being used now to print at up to 400m^2 per hour.

Inkjet printing has found use in the automotive industry in the on-demand printing of seat covers, in printing "walnut" interior trim, and in printing bar codes for parts tracking.

Other opportunities lie in the printing of plastic cards, using solvent or uv-curable inks, and in the printing of glass, for both functional and decorative reasons.

Applications that Resemble Printing

An application that could be called "three-dimensional printing" is rapid prototyping. Here, three dimensional objects are built up through printing of layer after layer of phase-change or uv-curable ink, or by printing a binder on

layers of powder. These systems currently build in the vertical dimension at up to 5cm per hour. Inkjet-based systems form only one of several digital approaches; their greatest limitation is the fragility of the printed parts. They are very useful for checking fit and even for preparing molds, especially for jewelry.

Inkjet printing is also finding its way into electronics manufacturing operations. Several companies offer legend printers, to print information on circuit boards, and others are developing inks containing micro metal powders to create the lands on circuit boards. Another approach involves the direct printing of resists onto metal-clad boards before etching. Solder bumps and printed solder interconnect towers are created by jetting molten solder. Polymer resistors are manufactured using inkjet technology as well.

More exciting still is the use of inkjet printing in conjunction with other printing technologies to produce diodes and transistors from semiconductive and conductive plastic materials. Arrays of such devices can form integrated circuits or backplanes for flat-panel displays.

Several universities and companies are developing just such devices. Transistors have been printed on flexible substrates to create microcircuits, including a processor equal in power to an 80486 chip, and thin, flexible displays have been produced using printed thin-film transistor backplanes. Developers point out that together with membrane keyboards and thin-film memory and storage, the possibility of a roll-up computer exists. More, importantly, printed components could dramatically reduce the cost of personal computers and make them accessible to far more of the world's population.

Organic semiconductors are far slower than their silicon-based equivalents, and the scale of printed componentry is about 200 times that of the best silicon chips. Still, these devices are suitable for many applications, and they will improve. One application for which they are quite suitable already is TFT display backplanes, as resolutions of only a few hundred dots per inch are needed and speed is geared to the response of the human eye, not to gigahertz processing.

Not only can display backplanes be printed by inket, but other display components as well. The polymers used in organic light-emitting diodes (OLED's), and the phosphors and filters used in liquid crystal, plasma, and other displays can be applied using inkjet technology. Products using this approach may appear as early as this year.

The application of inkjet printing to such microcircuits requires that the print system be exposed to chemically aggressive materials. Further, the requirements for accuracy and repeatability of drop volumes, velocities, and trajectories are exceptional. Great progress has been made in these areas and there is no doubt that inkjet will play a major role in this field.

Similar techniques can be applied to the manufacture of radio-frequency identification (RFID) tags for use in product tracking and in production of low-cost solar cells.

Inkjet technology is also used in photonics manufacturing applications, to produce micro-lens arrays for photonic switches and light waveguide splitters.

Applications Beyond Printing

Inkjet technology is very useful for micro-metering or very accurate control of coatings. It is also useful for the precise placement of drops of very regular size. In this last capacity, it has found use in chemistry and biology.

In chemistry, the technology is finding use in combinatorial chemistry, an automated technique in which many reactions are carried out in parallel and the products screened for useful properties. Inkjet printheads are used to place together discrete drops of reactants in various combinations. The technique was first used in drug discovery, but now finds use in screening for catalysts and phosphors as well. It is also used in DNA and peptide synthesis.

In the biosciences, inkjet technology has long been used in cell sorting and in protein deposition for immunoassays. More recently, it has found application in DNA probe microarray fabrication. Microarrays are used in gene expression analysis.

Experiments in tissue engineering and in drug delivery are also being conducted.

One of the most interesting applications is the generation of aromas. A device that uses inkjet technology, using sixteen ingredients to generate digitally a wide range of aromas, has been developed. The device is expected to find application in medical diagnostics for certain brain disorders, and ultimately in entertainment and consumer product testing and distribution.

Conclusion

Inkjet printing has found wide acceptance in many fields. Indeed, there are more inkjet printers in service today than all other electronic printing devices of all types combined.

While the desktop printer market is now maturing, there exist many opportunities for digital printing in commercial and industrial settings. Inkjet printing is uniquely suited to many of them.

Biography

Carl Thomas Ashley received an A.B. degree in Chemistry from Transylvania University in 1963 and an M.S. in Organic Chemistry from Marshall University in 1967. Since 2001, he has worked as an independent consultant in digital printing, as the principal of BIBLIO-tec. Prior to this, he spent twenty years in research and development at IBM and Control Data corporations and fifteen with Dataquest, BIS Strategic Decisions, and CAP Ventures, all consulting firms specializing in digital printing.