Predicted and Unpredicted Changes In Non-Impact Printing: 1981–2001

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"Future Directions of Non-Impact Printing Technologies" was the title of a panel discussion during the "First International Congress on Advances in Non-Impact Printing Technologies" in 1981. The 1981 status of non-impact printing establishes the context for the panelists' predictions. Evolution of the non-impact printing technologies and their applications from 1981 to 2001 are then compared with the panelists' predictions. Despite the fact that these predictions were not intended to cover a 20 year period, many were surprisingly accurate. Only a few differed from reality dramatically. The last section is entitled "Where To From Here?" The first part covers expansion of the present application range plus possible future applications. The second deals with a) technical advances in each non-impact printing technology that could improve performance and cost effectiveness and b) new non-impact processes under development or on the horizon plus basic science and technology areas that could have a significant impact on non-impact printing in the future.

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Introduction

The First International Congress on Advances in Non-impact Printing Technologies was held in June 1981. Computer output and word processing were the primary applications at that time. Electronic publishing and graphic arts were viewed as significant future application areas.

One of the sessions was a panel discussion entitled "Future Directions of Non-Impact Printing Technologies".[1] The panel's predictions along with those in papers presented at the congress will be compared with actual changes as a function of time. The assemblage of evolutionary information serves as the basis for projecting non-impact printing directions beyond 2001. They cover application areas and technologies, including complementary fundamental technical areas that could impact non-impact technologies significantly.

1981 Status

General

Impact (mechanical) printers dominated the computer output and word processing arenas. Fully formed character printers were suitable for low speed applications. Dot matrix devices covered moderate speed applications especially where graphics and functional color were required. Band/line/etched etc. type units were the impact high speed computer printers, albeit speed was limited to about 2,000 lines/min. 95% of the 340,000 installed in 1981 were impact printers. The rest were high speed (18,000-20,000 lines per minute) electrophotographic machines and low cost, noiseless, very low maintenance and cost direct thermal printers. The other non-impact printing technologies, ink jet, electrostatic and magnetic were not considered serious competitors because of their rudimentary technical status, with one exception – a high speed electrostatic page printer system developed by Honeywell Inc.[2] that used dielectric paper and liquid development.

Impact was preferred over non-impact printers because– reliability was much higher, cost/page and equipment cost were lower, the technologies were more highly developed and electronic and computer advances benefited impact as well as non-impact printers. However, non-impact printers are inherently noiseless, an important advantage in office areas. Moreover, speed, image quality and the ability to mix text and graphics were already superior to mechanical printers. Finally, R&D results indicated that critical characteristics would improve significantly in the near future including the ability to print in a wide range of colors.

Technologies

Electrophotography

Fifteen vendors offered 27 electrophotographic printers in 1981.[3] Price and cost/page varied markedly with speed. 63% used gas lasers and 30% employed optical fiber CRTs for exposure. Only one printer was equipped with a laser diode. All but two of the photoreceptors were inorganic and most of those (15) were composed of selenium or its alloys. Seven of the printers were based on liquid toner development. Most of the powder development systems were dual component. A few used monocomponent magnetic toner. Roller or drum fusion systems were built into 60% of the machines. The others used ovens, hot plates, infra-red and flash to fuse the toner images. Only 3 printers offered duplex. Resolution was 240 or 300 dpi.

It is often forgotten that electrophotography evolved along two paths during its early and intermediate stages. One of them was based on the now universally

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accepted re-usable photoreceptor drum or belt – indirect. The other combined the photoreceptor with the final substrate by coating paper with a white photoinsulator—direct. The process was much simpler—only 3 or 4 steps depending on the "fixing" method. Although equipment cost was low, cost/page was high, the "paper" did not look or feel like plain paper, quality and speed were limited and the "paper" tended to retain small amounts of the diluent used in liquid toner. As the cost of the "indirect" electrophotographic copiers and printers decreased including cost/page, and quality plus speed improved, the "direct" system became less and less popular. By 1981, "direct" electrophotographic copiers were no longer being manufactured.

Electrography

Electrostatic printing has had a similar dual history as have all the other non-impact printing technologies.

Direct Process

Paper coated with a very thin insulating film had almost the same feel, appearance and handling properties as plain paper. Printing required only three steps—charge, develop and fuse. Honeywell's page printing system (PPS) was competitive in high speed applications – 150 fpm, 300 dpi, 1 – 3¢/page and $200,000/printer. Diluent evaporated from the liquid toner was recovered and recycled. Spot color was planned for the next generation. Plotting applications were also attractive. Typical cost and performance characteristics of one product were –5¢/ft^2, 200 dpi, 8 fpm and $5,000/printer. Over time, much wider format plotters capable of spot color and higher resolution were developed.

Indirect Process

The electrostatic analog of the "conventional" electrophotographic process employs a reusable insulator in place of the photoreceptor drum or belt. Imaging requires only one step as opposed to two in electrophotography. Otherwise, the two processes are or can be the same. The ability to use plain paper is the major advantage.

Two approaches were in an advanced developmental state in 1981. In the first,[4] the insulating medium was charged uniformly followed by selective charge neutralization with an array of pin electrodes. Development, transfer and fusion were the same as in most electrophotographic printers. The manufacturing prototype printed at 40 fpm and 300 – 400 dpi. This machine was never commercialized. The second approach[5] employed a unique charging mechanism (ion deposition via plasma), combined the transfer and fusion steps using high pressure and utilized monocomponent conductive magnetic toner, thereby simplifying the printer and reducing its cost. Speed, resolution and price of these early printers were typically 50 fpm, 240 dpi and $30,000. Printers based on this second approach went on to considerable commercial success as intermediate speed computer output printers.

Magnetography

Unlike electrostatic images, development and transfer of toner from a magnetic image does not degrade the quality of the magnetic image. Consequently, it is possible to produce large numbers of copies per imaging step—a significant advantage in some applications. It is also much easier to edit or otherwise change a magnetic image than an electrostatic one. Additional attractive features are—long lived magnetic medium, high speed, simple inexpensive equipment, low cost/page and a mature technology. The major drawback was the color of the magnetic toner—black or dark brown, making high quality process color printing impossible. Here again, two approaches were possible and being pursued—one "direct" and the other "indirect".

Direct

The recording medium was either a ferromagnetic drum or belt. Magnetic heads produced the desired image that was developed with monocomponent magnetic toner. Transfer and fixing were combined via high pressure. 100 ppm and 250 dpi were demonstrated.[6] More than 10^3 copies were produced per imaging step and life of the magnetic medium was about 10^6 impressions. Shortly thereafter, a family of high speed monochromatic printers for computer printout and industrial applications was developed.

Indirect

DuPont developed a ferromagnetic material (CrO_2) with a Curie temperature of 120°C.[7] Highly localized heating of thin films produced positive or negative images that could be toner developed. 900 dpi was achieved using laser exposure. This approach appeared to have great potential. However, despite considerable research and development by several companies, no commercial products were introduced.

Thermography

Direct

In 1981, the only viable non-impact printing technology for low speed, low cost applications was direct thermal, for the reasons cited earlier. Thermal paper had been improved. Images were more stable. Sensitivity was higher, 64 gray shades and two colors were possible via exposure control. As a result, direct thermal printing was having a rebirth and thermal paper consumption was increasing 30% per year.

However, speed was only 2 - 5 ppm and resolution was limited to 250 dpi. In addition thermal paper does not feel, look or handle like plain paper and it is more expensive.

Indirect

The use of a thin polymeric ribbon coated on one side with a fusible pigmented layer as a means of producing thermal images on "plain" paper was described in a 1967 publication.[8] The ink side of the ribbon is in direct contact with the paper during the milliseconds a thermal head is in contact with the other side of the ribbon. The ability to print on plain paper, produce a wide range of colors and high optical density generated considerable interest. However, images appeared waxy. The paper had to be smooth and ribbons could be used only once increasing per print cost. Technical objectives were >10 ppm, 400 dpi and 64+ shades of gray via pulse width modulation. Laser exposure was not pursued for several years.

A project underway in the Oki laboratories was designed to eliminate the need for a ribbon by using a reinkable belt or drum. The ink was maintained in a molten state in a reservoir and the belt or drum was recoated after it was imaged. The first design[9] (Fig. 1) had a fatal flaw—the thermal head was behind the relatively thick paper. Resolution and edge sharpness were poor and energy requirements high.

Ink Jet

Although the fundamentals of jetting liquids have been known for over 100 years,[10] practical devices did not ap-

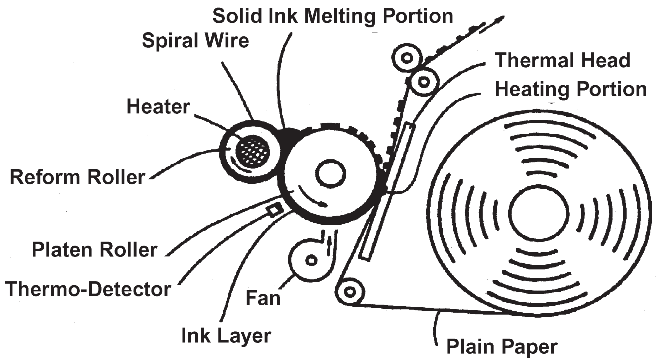

Figure 1. 1981 concept; Ribbonless Thermal Transfer Printer.

TABLE I.[13] Personal Computer Proliferation

Year	# Installed (M)
1982	2.8
1985	10.0
1986	20.0
1994	60.0
2001	500.0 (w.w.)

pear until the mid 1960s and intense developmental efforts got underway in the 1970s. Early printers exhibited all the problems associated with technologies that are low on the learning curve: e.g., poor reliability, nozzle clogging, start-up and shut down difficulties, mismatches between ink and paper, limited number of nozzles in arrays. However, results of research, development and engineering programs indicated that solutions to the many problem areas were feasible and imminent.

Speed of the drop on demand (DOD) approach was limited by the physics of the systems. Accordingly, those printers were aimed at office and word processing applications. Resolution was low, about 180 dpi and the number of nozzles per array was 12, Fig. 2, with 28 planned for next generation products.[11]

Continuous ink jet systems print at much higher speeds because the drop generation rate is 10 – 100 times higher than in DOD systems. (A detailed description of the various DOD and continuous mechanisms is beyond the scope of this article.) They are also much more complicated and expensive. Consequently, they are well suited to applications such as industrial labeling and marking on cans, packages, boxes, address labels, etc.

1981 Predictions[12]

It is well known that the accuracy of technical, applications and market forecasts decreases rapidly with time, especially beyond five years. Therefore, the predictions made by the panelists should not be judged too harshly twenty years later, especially when they could not have taken into account the dramatic effects of the 1981 introduction of IBM's personal computer (PC).

All PCs to that time were based on closed proprietary architecture thereby limiting competition. However, the IBM PC's architecture was open, making it possible for all clones to use the same software. This strategy encouraged competition and resulted in the extremely rapid proliferation of PCs beginning in the early 1980s.

Table I shows the growth in the number of installed IBM type PCs from 1982 – 2001. All these PCs needed printers. In 1986 alone, it has been estimated that 10^{12} pages were printed.

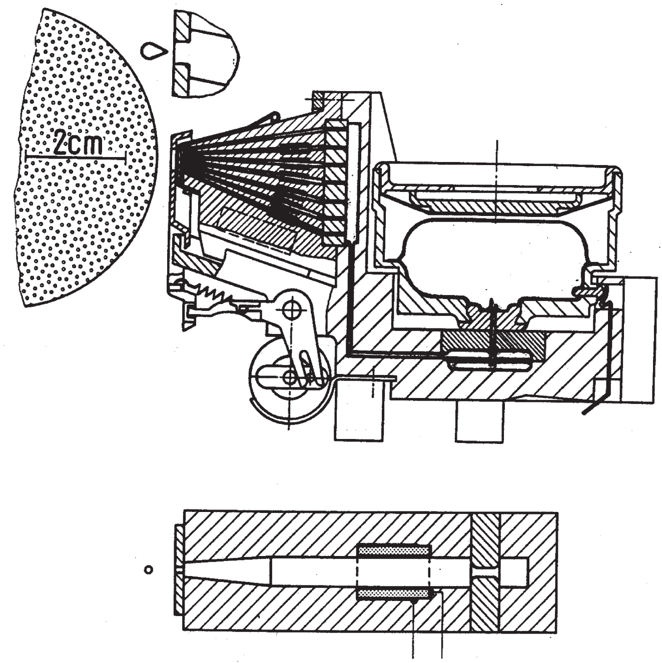

Figure 2. DOD printer—CIRCA 1981; similar design for color.

The general predictions that follow will be divided into those that came true and those that did not. Many of the technology predictions have been grouped together in order to decrease fragmentation.

General

Predictions That Did Not Come True

Ink jet, magnetic and electrostatic technologies will not catch up with electrophotographic and thermal technologies.
Ink jet surpassed thermal and eventually caught up with electrophotography in some applications. Magnetic and electrostatic technologies surpassed thermal but did not catch up with electrophotography.

Up and coming technologies are electrostatic, magnetic and plain paper thermal.
Ink jet potential was grossly underestimated.

Predictions That Did Come True

Long range applications will be electronic publishing, in-house printing and e-mail.
Given the state of knowledge in 1981, it would have been impossible to predict graphic arts including color proofing and short run color printing.

There will be major cost/performance improvements.
This is still work in progress but there have been quantum leaps forward.

Spot color will be followed by process color.
The rapid proliferation of color monitors made this prediction an obvious one. However, widespread availability of process color printers did not occur as rapidly as anticipated.

Initial inroads will be in the very high and very low speed computer output and office printing segments.
Impact printers could not match the speed and quality of laser printers or the low cost, low maintenance and long life of thermal printers.

TABLE II[13] NIP Growth: 1981–1998

Years	NIP Share (%)
1981	5
1985	13
1990	27
1994	50
1996	74
1998	94

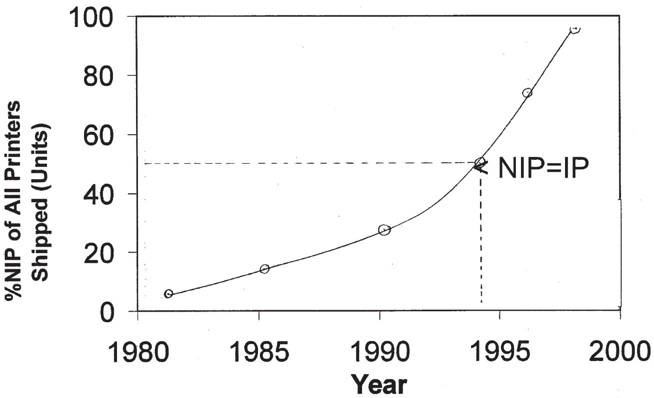

Figure 3. NIP share of computer and office printer market (units) 1981–1999.

Non-impact and impact printers will coexist through the 1990s.
Table II shows that it took about 13 years for the number of non-impact printers to equal the number of impact printers sold, longer than the optimists predicted and shorter than the impact printer advocates. Figure 3 is a graphic illustration of the competition between impact and non-impact printers over the 20 year time period.

Technologies

Magnetography

Mid-range and high speed applications will compete with impact and electrophotographic printers.
The lack of process color capability has limited application range. Two mid-range printers were developed in the early 1980s but their market penetration was negligible. In 1995, Nipson offered a high speed (872 - 8 1/2 × 11" pages per minute) printer that resolved 240 dpi, cost/page was <1 ¢ and machine cost was $350,000. By the late 1990s, resolution had increased to 480 dpi. A print on demand book press was introduced in 2001.

Electrography

Development of double sided dielectric paper will permit duplex printing.
It is possible that technical feasibility was demonstrated. However such a product was never manufactured so far as is known.

Plotter applications will become more sophisticated.
Direct electrography and thermal transfer were the only pen plotter alternatives during the 1980s. Electrostatics were faster than ink jet plotters but more expensive in the early 1990s. Direct electrostatic plotters are still used for CAD/CAM and a few specialized applications.

Will compete with impact printers in mid-range applications.
Ionography became the primary competitor for mid-range computer output in black and white. Resolution stabilized at 300 dpi, speed increased from 40 ppm to 125 ppm and printer cost varied from <$20,000 to $80,000 depending on system complexity. Use of monocomponent magnetic toner has limited application range. A color printer project was initiated during the mid 1990s.

Thermography

Dye sublimation/diffusion was not predicted nor were the major directions the other sub- technologies would take, especially "wax" transfer. Accordingly, brief chronologies of dye/sublimation/diffusion and "wax" transfer will follow the predictions.

Major short term application will be low speed, low duty cycle desk top printers.
80% of all non-impact printers shipped in 1982 were direct thermal. By 1984, market share had dropped to 50%, was less than 40% in 1987 and was limited to bar code printing in the early 1990s. Direct thermal is the method of choice for a growing number of point of sale printers, e.g., gas stations, credit card machines, etc..

Direct thermal will not be facsimile printer of choice
Direct thermal **was** the facsimile printer of choice throughout the 1980s and well into the 1990s. In 1987, 93% of all facsimile was printed on thermal paper. In 1992, the figure had dropped to 75% but the number of pages grew to 19.2 billion.

Spot and process color will be available.
One of the early advantages of dye sublimation/diffusion and "wax" transfer was their color capability which has improved over time.

Semiconductor laser exposure will improve resolution (800 dpi) and speed markedly. (20-25 fpm).
Laser exposure feasibility has been demonstrated. A recently announced thermal head produces 1200 dpi.[14] A. B. Dick marketed a 20 fpm thermal transfer printer in the mid 1990s.[15]

Ribbon improvements will make "plain" paper surfaces less critical.
There have been significant ribbon improvements. However, print quality is still paper surface dependent.

Personal computer output, office and industrial terminals and display will be long range applications.
Display never became an application for thermography. The other long range applications are covered in the brief chronologies of dye sublimation/diffusion and "wax" transfer technologies that follow.

Dye Sublimation/Diffusion Chronology

The major advantage is production of true continuous tone which opens up photographic and graphic arts applications. Early emphasis was printing of color TV images, pioneered by Sony Corp. High quality color proofers were developed in the early 1990s capable of resolving the equivalent of a 150 line screen. In the last two years, desk top printers for color proofing, photofinishing, business presentations and specialty products such as banners have been developed. Resolution varies with the application from 300 dpi to 2,400 dpi. Speed is ~ 1 ppm and equipment cost is moderate - $600 - $6,800.

"Wax" Transfer Chronology

Progress in the early to mid 1980s resulted in spot color at up to 400 dpi, IBM's low cost ($1,295) resistive ribbon thermal transfer (R2T2) printer (240 × 480 dpi

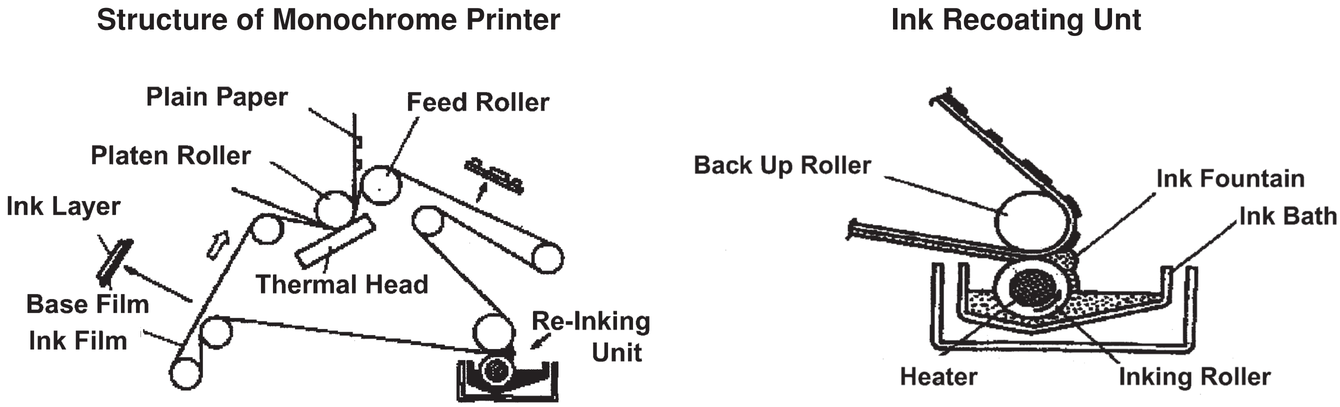

Figure 4. Improved Thermal Transfer Printer.

and >5 ppm) and a ribbonless thermal printer[16] with the thermal head properly located. Resolution and edge sharpness were still unacceptable because the substrate was too thick, see Fig. 4. By 1986 dot matrix printers were being replaced in applications such as tag, label and bar code printing. The ability to vary dot size via pulse width modulation led to process color copier/printers. Though still slow (1 ppm) resolution was 300 dpi, color gamut was broad—16M, and price was only $5,000. Continued development work ultimately resulted in a 20 ppm, 300 dpi process color printer that was priced at $40,000.[15] Cost/print was <40¢. Market share of the non-impact printing color market declined to 22% over the 1993-1996 period due to inroads by ink jet, laser and dye sublimation units. The primary present application is 300 dpi and 600 dpi bar code printing.

Ink Jet

The rudimentary state of the technology(ies) combined with the many problems made even conservative and qualitative predictions optimistic. As indicated below, the pace of technical progress exceeded even the most optimistic forecasts.

There will be large improvements in reliability, resolution, speed and printer prices.
Ink jet reliability became a non-issue due to: 1) introduction of disposable ink cartridges that included the nozzle arrays, 2) development of thermal ink jet, 3) ink, media and fabrication processes advances, 4) more and better software and microprocessors.

In 1980-1982, average resolution was 80dpi to 90 dpi. The 2001 range is 1200 dpi to 2400 dpi, a 27X increase. Print speed is a function of resolution, gray scale, number of colors, image size and equipment design. Highest present DOD print speed is about 40 fpm. Recent continuous ink jet advances have made it possible to print in color at more than 500 fpm. DOD units sold for $1,000 – $6,000 in 1982–1984. By 2001, a printer could be purchased for as little as $50 or as much as $1,000, a maximum price reduction of 20X.

DOD systems will replace dot matrix printers in SOHO type applications.
In 1982, 90% of desk top printers were dot matrix. Ink jet share was 1% and most of the rest was thermal. By 1990, ink jet share had increased to only about 10%. However, dot matrix market share was dropping fast (about 68%) due to competition from thermal transfer printers. Ink jet momentum began to increase in the early 1990s. Market share grew to nearly 30% and dot matrix's share shrank to about 45% by 1995. A year later the market shares were equal, about 35%. Thereafter, DOD became more and more dominant. 95+% of color desk top printers are now DOD units. The evolution of ink jet and the decline of dot matrix printers is graphically illustrated in Fig. 5.

Electrophotography

Cost/performance characteristics will improve.
"Reliability/uptime increased and maintenance costs and service call frequency decreased due to better and lower cost microprocessors, feedback controls, internal diagnostics and sensors; continuing software advances, multi-faceted R&D programs that led to, e.g., monocomponent color toners, improved development techniques and toners, lower cost exposure units and organic photoreceptors; and introduction of cartridges, especially the "all in one" types.

Speed range broadened to cover desk tops, networks and office, remote or distributed sites and centralized applications.

Resolution increased from 240 dpi to 300 dpi in the early 1980s to 2400 dpi.

Pulse width modulation, smaller particle size toners and higher resolution made it possible to produce images with 256 tones.

The advent of color PC monitors resulted in the introduction of spot color in the mid 1980s followed by process color in the 1990s.

Speed, resolution, gray scale and color are primary determinants of printer prices. Desktop B&W price was more than $3,500 in 1984. In 2000, the cost of a more capable printer was about $300. Desktop process color became available in the early 1990s at a price of about $12,500. By 2001, price had dropped to $2,500 - $3,000. When introduced in 1995 digital color presses (not predicted by the panel) sold for $400,000 and up. By 2001, similar units were available for $200,000 to $250,000.

Future applications will be word processing and graphics for high speed and personal computers.
This forecast was conservative. Desk top publishing, electronic printing/publishing, short run color printing, print on demand, variable data printing, photofinishing and color proofing are examples of the present application range.

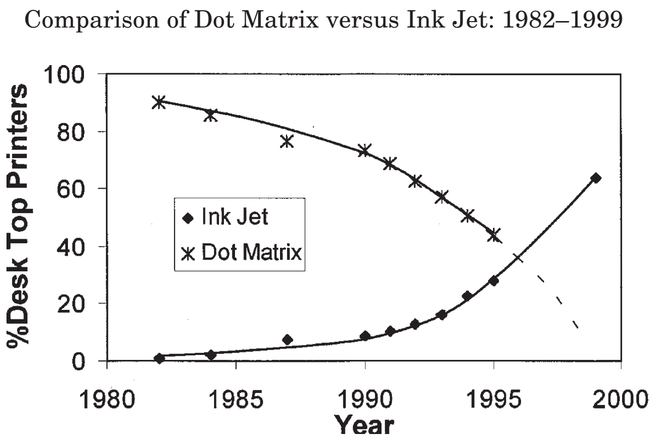

Figure 5. Desktop Printers (units); comparison of dot matrix versus inkjet: 1982–1999.

Where To From Here?

Future directions of non-impact printing will continue to be dependent on competitive and industrial trends on the one hand and general and specific technical advances on the other.

Industry Trends, Applications and Competition

Personal Computers

There will be dramatic decreases in size and cost. Displays will become more and more like paper, e.g., E-ink,[17] Gyricon.[18] Volume of hard copy will shrink as trend to “soft” copy grows. Personal computer printers will become smaller and cheaper. Scanning, facsimile, copying and printing – multi-functional capabilities will become routine. So there will be a need for very small, low cost printers and multi-function devices.

There are also near term substantial opportunities. In 2001, 500 million PCs are in use worldwide (another 300 million have become obsolete). Sales of PCs for 2001 are estimated at 130 million to 140 million. There are only 200 million non-impact printers in use worldwide. Many more have become obsolete. Furthermore, internet/web printing is a rapidly growing new market to which non-impact printing capabilities are exceedingly well matched.

Conventional Printing

The Upside

The trends to digitization, shorter runs, printing locally rather than centrally, fast turnaround and “green” operation favor non-impact printing technologies. Non-impact print quality is nearly the equivalent of offset. The ability to vary the content of successive images and to print on demand are significant advantages that will become more and more important. High speed non-impact printers are far less expensive than conventional printing presses. It has been estimated that by 2010, 80% of all hard copy normally printed conventionally will be printed by non-impact devices,[19] i.e., about 4×10^{12} pages.

The Downside

Reliability of non-impact printers requires further improvement. Cost/page is too high for many 2,000 – 5,000 page runs, and they are the most profitable. Advances by various segments of the conventional printing industry are continuing to raise the competitive bar. Examples are—computer to plate and computer to press technologies, Elcography[20] (no plates), waterless offset, water based and faster drying inks, press controls and diagnostics to reduce turnaround time and start-up and shut down waste.

Package Printing

The similarities to conventional printing are striking. Virtually all the conventional printing processes are used, runs are becoming shorter and print content targeted at certain groups of individuals is becoming more popular. Reliability and print cost per unit area will continue to be primary evaluation criteria and more toners and inks for non-paper substrates will be required.

Photofinishing

Ink jet is already making significant inroads, a trend that will intensify as digital camera use increases. By 2004, the number of digital and silver halide cameras sold is expected to be equal. In addition, means for extracting digital image information from exposed silver halide film without wet processing has been demonstrated. This capability will create a need for centralized digital photofinishing printers. At high speeds, laser units could be more cost effective than ink jet printers.

Specialty Application Areas

Wide format color ink jet printers appear to be uniquely suited to the needs of enterprises interested in printing on substrates such as fabrics, wallpaper, floor coverings, banners, large area signs. It appears likely that ink jet will continue to be the technology of choice in these application areas.

The ability to deposit exceedingly small amounts of a wide range of materials in precise locations is opening new opportunities for ink jet printers, e.g., resists for electronic circuits and printing plates,[21] color filters for flat panel displays,[22] organic transistors and other organic electronic components,[23] cDNA microarrays to evaluate drug candidates, etc.

Possible Advances In Non-Impact Technologies

Technical progress is not only limited by fundamental scientific barriers and availability of critical materials but also by the levels of effort (people, money and facilities) exerted over time. This latter limitation is a function of the perceived competitive advantages and commercial opportunities that could ensue from the potential technical progress.

The advances to be described briefly for each of the non-impact printing technologies are possible because neither scientific barriers nor lack of critical materials constitute limits.

Magnetography

Application range is severely restricted by poor color and gray scale. The advent of small, inexpensive, high energy laser diodes makes high speed Curie Temperature imaging possible, resulting in high resolution and excellent gray scale.

Magnetic organic materials have been under study in Japan and the United States for many years. Colorless cobalt doped titanium dioxide was reported recently.[24,25] Magnetic color toners are used to produce process color images in a different system.[26]

Electrography

A ferroelectric instead of an insulating medium would make it possible to produce large numbers of replicas per imaging step. Organic and inorganic ferroelectric materials are known and there is considerable R&D on new materials and printing on ferroelectric media.[27] Color toners like those used in laser printers along with appropriate development, transfer and fixing steps would result in excellent process color prints.

Thermography – "Wax" Transfer

Previous attempts to eliminate ribbons led to unacceptable resolution and edge sharpness. Exposing a recoatable, rugged and transparent substrate with high power laser diodes should result in excellent resolution and edge sharpness. Use of "ink" cartridges is already well established and could permit modular designs tailored to special applications. The advanced technical status of polymer technology makes it highly probable that a non-waxy "ink" could be developed.

Ink Jet

Progress has been extraordinarily rapid over the last ten or so years. Evolutionary developments can be expected in the near future, e.g., wider and wider nozzle arrays, new and/or improved jetting mechanisms, higher resolution, higher speed color printers, portable low cost printers.

Electrophotography

Image quality, resolution, color gamut, speed and cost/performance improvements have been remarkable especially considering that it takes seven consecutive steps to print each and every image. As indicated earlier, however, to compete successfully in the conventional and package printing as well as photofinishing industries will require reliability, cost/print and other properties improvements well beyond current levels. It appears that the seven process steps could impose fundamental limits on cost and performance characteristics. If each step is 95% "perfect", the entire process is only 70% (0.95^7) "perfect". If a value of 98% is assumed, the entire system is still reduced to 87%. It follows that further significant technical progress will depend on reducing the number of process steps.

There appear to be technically feasible possibilities. One is to charge and expose or to charge, expose and develop simultaneously. Transfer of electrostatic images under the influence of an electric field during exposure is a well known concept. Were the insulating film ferroelectric, it might be possible to produce a large number of prints per imaging step. A second is to replace photoreceptors with organic photo-voltaic media or photosensitive films that undergo large reversible changes in dielectric constant. A third is to develop with a very low vapor pressure, 100% photopolymerizeable liquid toner. The wetting properties of the toner and the electrostatic image bearing medium could ensure that complete transfer to the final substrate occurs. UV exposure would fix the image completely and rapidly.

New Processes

The technical and practical advances that have been and continue to be forged in the various non- impact printing technologies are due in no small measure to progress in the materials, physical, electronics and computer sciences and technologies. It is highly probable therefore, that more dramatic advances and new processes will also derive from these and other fundamental sciences and technologies. Examples of some newer areas that appear relevant are nanotechnology,[28] self assembling materials,[29] biomimetics (especially chemistry of vision), microelectro-mechanical systems, thin film technology (e.g., layer on layer deposition) and new polymers (e.g., dendrimers, photoreactive).

Near term, Elcography appears to be close to commercialization. Digital packet printing[30] was proposed some years ago and may now be under active development. Reusable computer to press techniques are already available commercially. However, they require medium removal and re-application. If the computer to press medium consisted of a photosensitive medium wherein the photochemical reaction were reversible, it would not be necessary to remove and re-apply the imaging medium. Such a material would also permit highly localized rapid addition, removal and/or modification of the image.

Summary

In 1981, the modest technical status of non-impact printing limited applications to computer output and office printing – areas dominated primarily by impact printers. The introduction of the open architecture IBM personal computer in the same year led to the extraordinarily rapid growth of the entire industry over the next several years including printers, displays, keyboards, storage devices, etc. The predictions made at the first NIP Congress could not have taken the IBM innovation into account, and they were not intended to cover a 20 year period. Nonetheless, they were surprisingly accurate, although some were conservative.

It did take more than ten years for non-impact printer sales to catch up to and surpass impact printer unit sales. The rate of ink jet technical progress was grossly underestimated and of thermal and electrostatic somewhat overestimated.

Technical advances in electrophotography and magnetography were much as predicted, except for the advent of color capable digital presses and high speed black and white industrial printing, including an on demand book press.

By the mid1990s and beyond, image quality, reliability, cost effectiveness and process color had improved so much that additional more challenging applications seemed feasible.

Trends to shorter runs, digitization and print on demand in the conventional printing industry made non-impact printing an attractive possibility. However, the conventional printing industry was and is also progressing technically, e.g., computer to plate, computer to press and plateless techniques.

In addition, reliability and cost/page of non-impact printers are still not equivalent to offset systems. Digital cameras have created a growing demand for printers capable of producing photographic quality prints. Ink jet, dye diffusion, thermal and electrophotographic printers now dominate this market niche. Package, textile and wide format printing are also significant application areas in various evolutionary stages.

The future of non-impact printing will be a function of trends in the various application areas and technical progress in the non-impact printing complementary and competing technologies.

There will be dramatic changes in personal computers, resulting in less hard copy. Inroads in the conventional printing arena, photofinishing, textile and wide format printing will increase over time. Package printing is still a largely untapped area. Although small in terms of volume, a number of specialty ink jet applications are being implemented.

Fundamental technical considerations lead to the conclusion that major improvements in all the non-impact printing technologies are still possible and feasible. Whether or not technical organizations will choose to perform the R&D work required will depend on the perceived potential competitive advantages over time. When performing such assessments, it will behoove organizations to take into account relevance of general scientific and technical advances in areas such as nanotechnology, self-assembling materials, photosensitive polymers and dendrimers and microelectromechanical systems.

Acknowledgment. It seems altogether fitting and proper in commemorating the 20th anniversary of the first Congress to pay tribute to the individual and the organization that, as early as 1980, recognized the need for and value of an international congress on advances in non-impact printing technologies. Dr. Arnaldo Pasini, Vice President – Research (now retired) of Olivetti S.p.A., served as the General Chairman and was instrumental in converting an idea into a reality. His company provided not only encouragement and peripheral personnel but also financial support. The sixteen NIP Congresses that have followed might not have occurred without their trail blazing effort.

References

1. A. H. Sporer, *Advances in Non-Impact Printing Technologies for Computer and Office Applications*, Van Nostrand Reinhold Co., New York, NY, 1982, p. 1333.
2. E. R. Truax, Ref. 1, p. 1368.
3. M. M. Shahin, Ref. 1, p. 1350.
4. M. Kimura, I. Kondo, M. Horie, and H. Takahashi, Ref. 1, p. 622.
5. R. A. Fotland and J. J. Carrish, Ref. 1, p. 685.
6. P. Bernstein and J. P. Lazzari, Ref. 1, p. 743.
7. W. Bindloss, E. F. Haugh and F. C. Zumsteg, Ref. 1, p. 756.
8. R. D. Joyce, S. Homa, Jr., *Proc. Fall Joint Computer Conf.*, 1967, p. 26.
9. S. Nakaya, A. Watanabe and K. Tsuji, Ref. 1, p. 1341.
10. J. W. S. Rayleigh, *Proc. London Math Soc.* **10**, 4 (1878).
11. J. Heinzl, Ref. 1, p. 1190.
12. A. H. Sporer, Ref. 11, p. 1333.
13. Market/business figures published in many trade journals and documents were used to derive all the numerical values in this article.
14. H. Terao, T. Nakatani, N. Tsushima, and I. Hibino, *Proc. IS&T's NIP 17th Int'l. Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 2001, p. 504.
15. Anon., *Print on Demand Bus.*, 16 (June 1995).
16. I. Nose, T. Takeda, S. Kuroe, H. Masaki, and T. Tanoshima, *Proc. SID* **27**, 53 (1986).
17. I. Morrison, *Proc. IS&T's NIP 17 Int'l. Conference on Digital Printing Technologies*, IS&T, Springfield, VA, 2001, p. 523.
18. R. Sprague, Ref. 17, p. 519.
19. M. Bruno, *Image Printing Digest*, 4 (1998).
20. A. Castegnier, *Proc. IS&T's NIP 12 Int'l. Conf. on Digital Printing Technologies*, IS&T, Springfield, VA, 2001, p. 276.
21. H. Sirringhaus, T. Kawase, R. H. Friend, T. Shimoda, M. Inbasekaran, W. Wu, and E. P. Woo, *Science* **290**, 2123 (2000).
22. S. Wu, *MRS Bulletin*, 970 (2001).
23. P. Calvert, *Chem. Mater.* **13**, 3299 (2001).
24. Y. Matsumoto, M. Murakami, T. Shono, T. Hasegawa, T. Fukumura, S. Kawasaki, P. Ahmet, T. Chikyow, S. Koshihara, and H. Koinuma, *Science* **291**, 854 (2001).
25. Anon., *C&E News*, 62 (August 27, 2001).
26. M. Slot and R. Van der Meer, *Proc. IS&T's NIP 17th Int'l. Conference on Digital Printing Technologies*, IS&T, Springfield, VA 2001.
27. S. Reuter, A. C. Hubler, S. Franke, K. Wolfe, and M. Schonert, Ref. 26, 629.
28. *Scientific American, Spec. Issue: Nanotech*, (September 2001).
29. *Proc. ACS Div. Polymeric Materials: Science and Engineering Symp. on Macromolecular Self Assembly at Surfaces and Interfaces*, **84**, 18 (2001).
30. P. E. Salmon, US Patent 5,153,617 (1992).