บทความวิชาการ

การพิมพ์ระบบดิจิตอลบนวัสดุสิ่งทอ

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บทคัดย่อ

เทคโนโลยีระบบดิจิตอลได้ส่งเสริมคุณภาพชีวิตของมนุษย์มายาวนานมากกว่า 50 ปี และเครื่องพิมพ์ระบบดิจิตอลได้รับความนิยมอย่างแพร่หลายอย่างมากกับวัสดุสิ่งพิมพ์ประเภทกระดาษ แต่สำหรับการพิมพ์ระบบดิจิตอลบนวัสดุสิ่งทอพึ่งจะได้รับความสนใจเมื่อไม่นานมานี้ ประโยชน์ของการพิมพ์ระบบดิจิตอลบนวัสดุสิ่งทอที่เห็นเด่นชัด คือ การที่ทุกขั้นตอนตั้งแต่การออกแบบจนถึงการจัดจำหน่ายสามารถส่งข้อมูลผ่านระบบดิจิตอล เทคโนสารสนเทศ ซึ่งทำให้ผู้ผลิตสามารถตอบสนองความต้องการของลูกค้าได้อย่างรวดเร็ว และระบบการพิมพ์ดิจิตอลก็สามารถสร้างผลงานสร้างสรรค์ที่เป็นเอกลักษณ์โดยไม่มีข้อจำกัดทางด้านจำนวนสีและจำนวนสกรีนที่ต้องใช้เหมือนกับการพิมพ์แบบดั้งเดิม ดังนั้นการพิมพ์ระบบดิจิตอลบนวัสดุสิ่งทอจึงให้คุณภาพของงานพิมพ์ทั้งทางด้านความสวยงามและความคิดสร้างสรรค์

คำสำคัญ: การพิมพ์แบบไม่สัมผัส การพิมพ์อิงค์เจ็ท ระบบพ่นหมึกแบบต่อเนื่อง ระบบพ่นหมึกแบบตามสั่ง

ภาควิชาวิทยาศาสตร์และเทคโนโลยีสิ่งทอ คณะวิทยาศาสตร์และเทคโนโลยี มหาวิทยาลัยธรรมศาสตร์

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Digital Textile Printing

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ABSTRACT

Digital Technology has enhanced human lives for over the past 50 years. The huge achieving digital printing on paper has been appeared for many years, but it is only during the past decade that the digital printing of textiles starts to become gradually popular. The main advantage of digital textile printing is based on the digital management system, where the manufacturing and distribution processes are implemented and controlled digitally. With the use of information technology, manufacturers can communicate with individual consumers through internet and customers' printing demands are met immediately. Unlike conventional textile printing, digital printing cycle times are shorter and sample production can be done immediately. Furthermore, digital textile printing has led to new opportunities and created new markets, in which conventional textile printing methods are unable to accomplish. Digital textile printing can generate many new image-making possibilities without the limited numbers of colors or screen size of conventional printing. Digital textile printing also expands the concept of design aesthetics by its ability to yield more creative outcomes in textile printing industry.

Keywords: non-impact printing, inkjet technology, continuous inkjet, drop on demand printing

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Introduction and Historical Background

Digital Technology has enhanced human lives for over the past 50 years. Now we are surrounded by television, computer, telephones, camcorders, digital camera, laser barcode readers, etc and many houses possess computers with access to internet. The textile printing industry has also adopted this technology particularly computer aided design (CAD) to assist design products and computer aided manufacturer (CAM) to aid production machine settings and screen productions [1]. Though recently the cost of computers has dropped dramatically, their functions have been improved with powerful algorithms and software systems. Now the digital information can be stored and implemented electronically and mechanical storage devices are no longer required. Therefore, the main advantage of digital textile printing is the digital management system, where the manufacturing and distribution processes are implemented and controlled digitally. With the use of information technology, manufacturers can communicate with individual consumers through internet and customers' printing demands are met immediately. Unlike the conventional textile printing process, digital printing cycle times are shorter and sample production can be done immediately as shown in Figure 1.

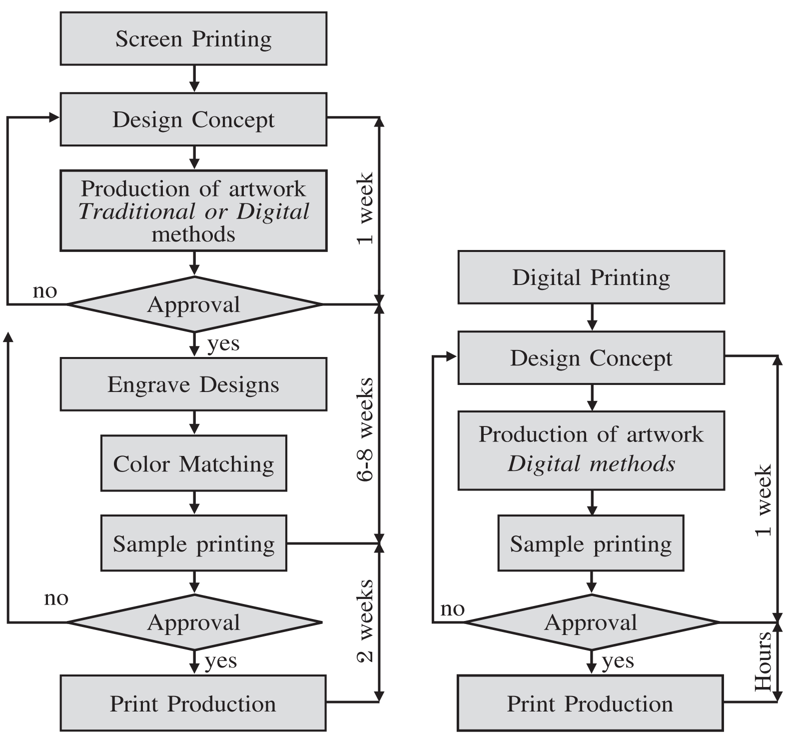


Figure 1 Screen printing and digital printing time scales (adopted from [2]).

The huge achieving digital printing on paper has been appeared for many years, but it is only during the past decade that the digital printing of textiles starts to become gradually popular. The growing interest in digital textile printing is based on the development of inkjet printer technology. Digital textile inkjet printers on fabric are similar to the desktop inkjet printers. The main differences between desktop inkjet printers and textile inkjet printers are kinds, concentrations and physical properties of dyes [3]. The first application of digital textile printing was with carpets in which a patented technology exclusively to Milliken of Spartanburg, South Carolina, USA [4]. This was performed in the 1970s and it made use of a pulsed air jet to carry ink to the carpet's substrate. Milliken advanced this technology from its early 10 dpi resolution to over 70 dpi. Today most printed commercial carpets are digitally printed. Since then both hardware and software have been improved continuously. However, the first true inkjet printer for fabric was developed by Stork in 1991, named Trucolor TCP2500, which used special reactive dyes as an ink [5]. It offered faster producing samples and pre-production prints for customer approval.

Now the worldwide production of printed textile material is over 34 billion square meters per year, but it is dominated by rotary screen printing [6]. There are two major drawbacks holding digital textile printing back from having a major impact of worldwide print production: speed and cost of the color inks. Commercially digital textile printers can operate 150 square meters per hour whereas rotary screen printers can easily reach speeds over 1000 square meters per hour [3]. However, the result of convergence of time, technology, and connectivity are that the companies are required to develop varied products frequently with shorter expected product life cycles. The run lengths of textile printing jobs tend to decrease dramatically. Product Designers have to provide more options and retailers demand more choices and fewer inventories. A quicker restocking of popular designs can increase business profitability. As run lengths decrease, the cost of traditional screen printing increases. Digital printing can be cost-effective against screen printing for shorter run lengths as shown in Figure 2. The cost per square meter for digital printing is relatively flat and does not change much with volume. With conventional printing, the cost of engraving screens and setup must be amortized over the length of the print run. When a printing product is above 1000 square meters, it is economical to print on screen printer. Below that scale, digital printing can be cost effective.

Moreover, creative designs must be digitally printed because even the largest screen printers can have no more than 12 screens, which equal to a limitation of 12 colors. With digital printing, there can be an unlimited number of colors in design allowing much more than 12 colors in a specific design. Furthermore, each of many textile printing markets has their own requirements for image quality, color, and fastness characteristics. For instance, image quality and fine line printing is more necessary for silk accessories, and color and fastness qualities are more important for swimwear. The silk accessories market has to be digitally printed because of the inherent short run lengths and relatively high value to the customers. The swimwear market is also amenable to digital printing because of the short run lengths and varied designs. However, the inks must meet the fastness requirements for chlorine, light, and salt water exposure.

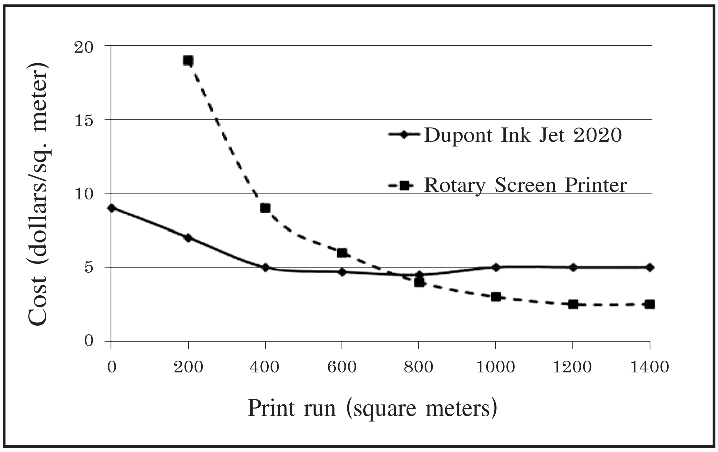


Figure 2 The screen and digital printing setup cost (adapted from [3]).

The cost of the inks is a major issue because the development cost of inks for digital textile printing is high. Actually, inks used in digital printing have been adapted from traditional dyeing and printing routes. The inks have to be specially developed for the fabrics and ink type changeover is time consuming. Also, Ink developers have to concern about the textile substrate, the pre-treatments given to the substrate, the print head technology, and the post-treatments. An overview about these factors can be found in [7]. However, if the market shares of textile digital printing are increasing, as the ink volume increase, the manufacturing costs decrease, allowing the reductions in pricing. Furthermore, recently there are many Chinese ink suppliers coming into the market. With the technology, digital printing inks are now available for most textile substrates with improved flow and fastness properties. These inks are also available from varied manufacturers. The recent novelty is the creation of silver and white colors to extend the range of solvent inks for large-format printers, which are invented by Mimaki [8]. Combining silver with other colors, Mimaki claims that gold and bronze also can be achieved. In addition, nanotechnology tends to be used more frequently in developing digital printing inks. It helps reduce clogging and enhance the control over drop formation. There is research work for the micro-encapsulation of nanoparticles to impart antimicrobial, fragrance, and other properties to inks [9].

Textile digital printing first started as a prototyping tool and a machine for printing samplings, the printing of flags and banners, and small batches of fabric for niche market productions. However, for the past 12 years, we have seen some breakthroughs in the use of digital printing on textile materials [10]. There are many more commercial machines, much enhancement in ink systems, and significant advances in software systems. The development of digital technology has impacted the workflow of manufactured printed textiles. The range of application is now very widespread, and mass-customization is a potential goal. It is necessary to appreciate that there are two main textile digital printing workflows: digital strike-off printing and full digital textile production that have consequently led to a more streamlined and effective production environment [3]. Instead of using conventional printing to make strike-offs, in which engraving processes are required, manufacturers tend to use digital printers to create strike-offs. By comparison, the digital strike-off workflow process obviously eliminates extra engraving costs, which can save companies a lot of time and money per year [11]. And this workflow is the most popular use of digital textile printing today and has continued to gain popularity.

Conventional Printing vs. Digital Printing

Currently flatbed screen printing and rotary screen printing are the most popular production technologies and share more than 80% of the total printing market. Rotary screen printing accounts for nearly 65% of total printing works. However, digital technologies are great important for textile's supply chain management. Every stage of textile process, whether product design, product development, communication of product data through the supply chain, control of manufacturing processes, testing, logistics and the management of inventories, is facilitated by digital information. For instance, by specifying color digitally at the beginning of the product development process, it becomes possible to rethink the product development process. Digital printing of textile materials can provide samples of the right colors and visual texture for phototyping and photoshoots. This offers the possibility of shortening lead times for product development and maintaining confidentiality about products until decision to order bulk has been made. Kneeling identified key characteristics of digital printing technology as [4, 12]:

- Variable Data. The input is not limited by size nor does it needs to repeat because the data is gotten from an electronic file.
- Non-contact with substrate. The ink is dropped onto the substrate, making it versatile to print on any chosen surfaces.
- Multi-color. Based on the cyan-magenta-yellow-black (CMYK) color gamut, millions of colors can be printed without the requirement for a color kitchen.

- No moving parts. Printer motions are restricted to oscillators within heads and a system to move the heads in relation to the substrate. It is the ink that moves during printing, not a mechanical machine. Therefore, inkjet printers are inherently reliable.
- Speed. The printing rates depend on resolutions, the heads of inkjet machines, the types of printing required, etc.

In fact, inkjet printing is fundamentally different from other conventional printing techniques, not only because of non-contact mechanics of the print heads but also in which the individual colors of a design are developed. In conventional textile printing, it uses one screen for each color in the design for which individual print pastes are created to match the desired shades. In inkjet printing, a great deal of computation is necessary to create each color in a design and this continues as long as the machine is printing the textiles. The summarized comparison between inkjet printing and conventional screen printing is shown in Table 1.

Table 1 The comparison between inkjet printing and screen printing.

Factors	Inkjet Printing	Screen Printing
Operational procedure	*Simple*	*Complicated*
Flexibility	*High*	*Limited*
Setting time (design to print)	*Few hours*	*Several weeks*
Energy consumption	*Low*	*Medium*
Waste water production	*2 liters per m fabric*	*25 liters per m fabric*
Production speed	*Much slower than rotary screen printing*	*High*
Consumption of chemicals	*Low*	*High*
The range of colors	*Millions of colors*	*Limited to numbers of screens*

While conventional screen printing has developed simple technologies with time, the technology demands on textile digital printers are very high.

Inkjet Technology [4]

The digital printing of textiles is based on the development of inkjet technology. Inkjet technology is the process in which the design colored pattern is created by projecting the tiny drops of different color inks into predetermined micro-arrays onto the substrate surface [1, 13, 14]. Each of these arrays is presented by one picture element of the design called pixel. Printing color digitally engages printing pixels in which each pixel makes up of different ink colors. Inkjet technology enables the delivery of liquid ink to a medium whereby only the ink drops make the contact with the medium [14]. Therefore, it is a nonimpact printing method. The foundation theory behind this technology was created by Lord Rayleigh in 1878 [15]. Inkjet technology is composed of three basic components: print head, ink, and medium or substrate [16]. Generally, a set of inks consists of at least three primary colors, which are cyan, magenta, yellow, and optionally black. It is so called CMYK. The proportion of each primary color in any area of a print determines the perceived overall color in that particular area.

Inkjet printing technology can be classified into two main categories: continuous inkjet (CIJ) and drop on demand ink jet (DOD) as shown in Figure 3. Most office printers make use of thermal print head; however the majority of textile inkjet printing technology is piezoelectric because this technology gives greater robustness and flexibility to machine builders. The useful reviews of inkjet technology for textiles are stated in [13, 17].

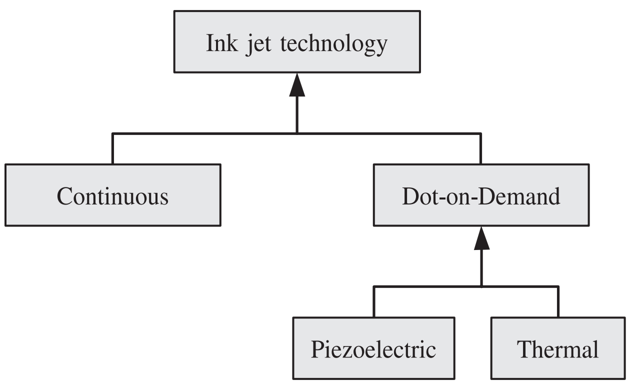
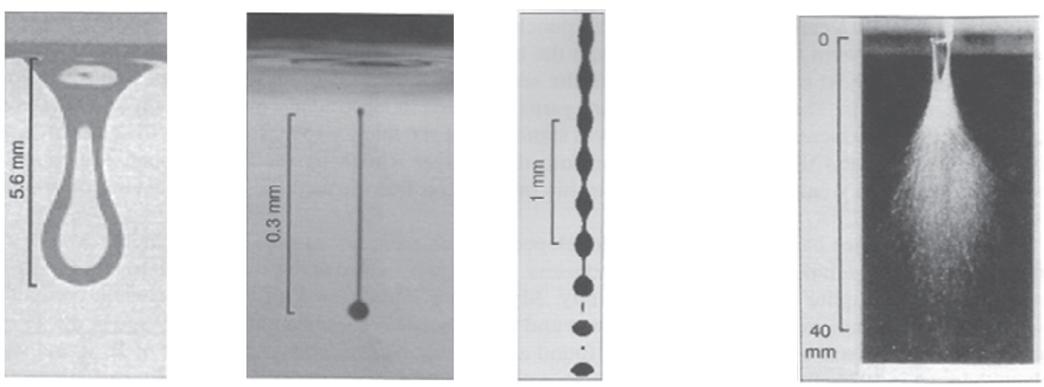


Figure 3 The classification of ink jet technology for textile printing (adapted from [3]).

The fundamental concept of digital printing process can be understood by observing a dripping tab as in Figure 4(a). Each drip allows a droplet to fall on the substrate below. If the movement of the faucet is controlled, the droplet can be fallen on the substrate in a controlled way. If additional controls are employed so that for each position of the faucet, the droplet can either fall or not fall, then this process mirrors the digital printing process. With digital printing, the drop sizes are much smaller than those coming from a dripping tap. As the flow rate is increasing, the system switches from drop on demand (Figure 4(b)) to continuous inkjet (Figure 4(c)) and to atomization (Figure 4(d)). The drop on demand mechanism shows the drop with its long tail. Managing the tail so that it does not degrade the image must be controlled by both inks and print head manufacturers. The continuous inkjet mechanism shows the continuous inkjet emerging from a nozzle breaking into droplets. Controlling where the droplets either fall or not fall is the challenge for this mechanism. The atomization mechanism represents a higher flow rate and it is possible to control individual droplets. This mechanism has led to the design of pulsed jet machine where the print head emits either an atomized spray or not. More detail of each mechanism will be discussed in the next section.



(a) dripping faucet (b) drop on demand (c) continuous inkjet (d) atomization

Figure 4 Fluids from a nozzle (adopted from [4]).

1. Continuous Inkjet (CIJ)

In CIJ technology, a high pressure pump directs liquid ink from a reservoir through a gun body and nozzle, which create a continuous stream of ink droplets as shown in Figure 5. CIJ technologies manage the movements of these drops electrostatically as the drops are given an electrostatic charge and are steered either to the substrate or to a recirculation system. The earliest work on textile inkjet printing made use of CIJ technology, but commercial utilization has been slower than the DOD technology.

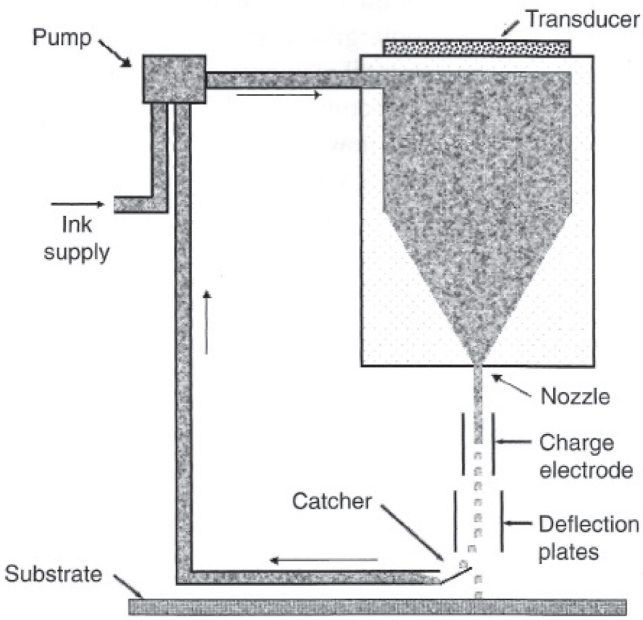


Figure 5 The continuous inkjet (CIJ) concept (adopted from [4]).

2. Drop on Demand (DOD) Inkjet

This technology provides mechanisms for delivering a drop of ink when there is a demand. This demand is generated by the printing software whereas for each pixel the instruction is either to fire a drop or not to fire. Then the drop of ink falls to the substrate under the influence of gravity and show as a dot on the surface as shown in Figure 6. Drop sizes are generally measured in picolitres. Typically, drop sizes are 20-30 pl., but there is an attempt to make the head that can produce the drop sizes below 10 pl. The decrease in drop size claims to give the better resolution and reduce the problems of pixilation. Furthermore, the flow rate of ink onto the substrate is also reduced. There are two main drop ejector mechanisms used to generate drops: piezoelectric and thermal inkjet.

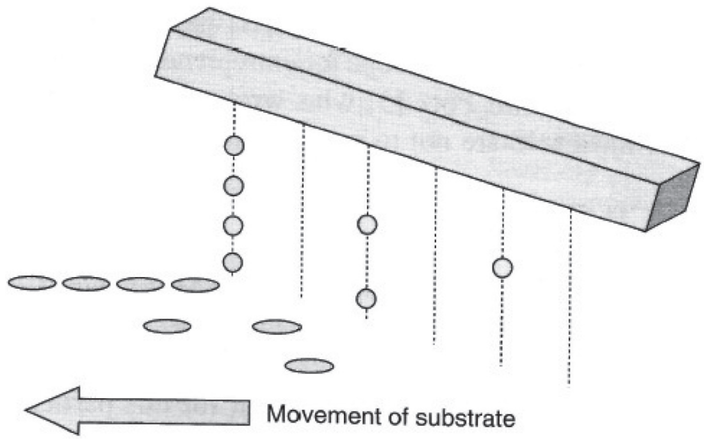


Figure 6 The drop on demand (DOD) concept (adopted from [4]).

2.1 Thermal Inkjet or Bubblejet

This technology is commonly known as Bubblejet by Canon of Japan, and Thermal Inkjet or ThinkJet by Hewlett-Packard. For thermal DOD inkjet technology, the droplets of ink are forced out of the nozzle by heating a resistor that makes an air bubble to expand. When the bubble collapses, the droplet breaks off the system and returns to its original state as shown in Figure 7. However, the heating cycles elevate the temperature of the inks and this may lead to the inconsistent colors or the inks can be damaged by the heat so that it clogs the nozzle. Also, the explosive ejection of the ink can create splattering that reduces the print quality.

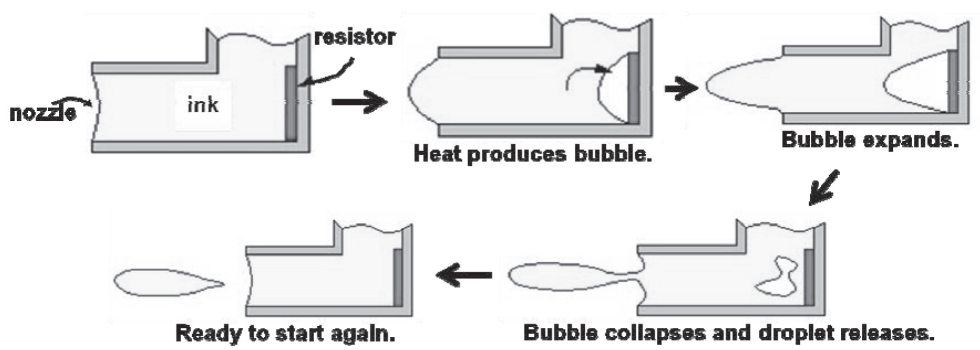


Figure 7 The Thermal Inkjet/Bubblejet concept (adopted from [18]).

2.2 Piezoelectric Inkjet

In Piezoelectric Inkjet technology, the ink chamber is made from a piezo-electric material, so the volume of the chamber is changed when an electric field is applied. When the electric field is turned off, the chamber shape snaps back to its normal and this draws ink in from the supply channel as shown in Figure 8. Since the ink is not heated to form a bubble, there are fewer constraints to affect ink formulation, and piezoelectric inkjet heads tend to last longer than thermal inkjet heads. Also, piezo heads yield more control over drop production than thermal heads. For these reasons, piezoelectric inkjet is the most popular for digital textile printing. The major head manufacturers for this technology are Aprion Magic piezo DOD, Epson piezo DOD, Konica, etc.

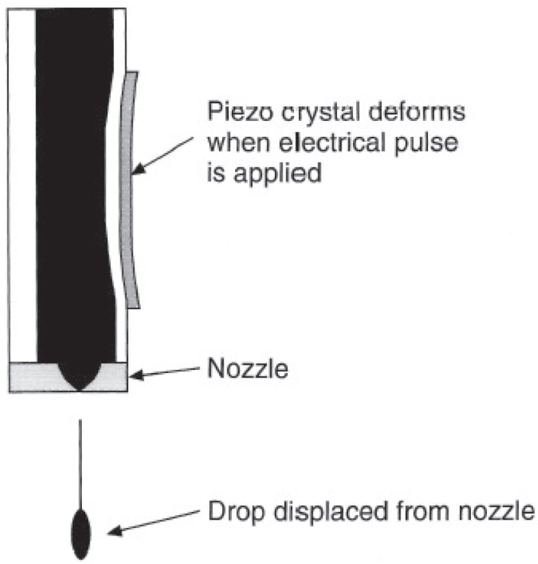


Figure 8 Piezoelectric DOD concept (adopted from [4]).

Conclusion

Textile digital printing is a rapidly developing field. Inkjet textile printing has been growing whereas the growth in conventional textile printing seems stagnant. The growing interest in digital textile printing is based on several factors. These factors are rapid transformation from computer aid design into printed patterns, easy selection of colors, fully exclusion of screen-engraving processes, a printing cost independent of the volume of production, extreme reduction in the number of operations required, small installation footprint, and decreased environment pollution. Nevertheless, digital printing still faces some severe limitations such as slow printing speeds and the price of the inks.

Today's markets changes very fast and customers are becoming more demanding. Digital textile printing can yield the production of goods and services to match individual customer's needs. People can make himself to be unique. Design cycle times are reduced and sample production has to be done right away. As the length of textile print runs decreases, and the demand for short-run production and just-in-time delivery increases, digital printing yields the cost-effective solutions. As digital print technologies improve, offering faster production and larger cost-effective print runs, digital printing will grow to become the technology that provides the majority of the world's printed textiles. In additions, the academic works from both textile and computer researchers have provided strongly support for the usage of digital technology in the textile industry. It is the fact that the growth of using computer technology in every field of textile industry will be considerably and continuously increased. Therefore, it is necessary for textile manufacturers to understand the principles and advances of the digital technology used in textile industry in order to use this knowledge in their practical operations.

Table 2 The summary of strengths and weaknesses of digital printing.

Strengths	Weaknesses
- Very fast design changes - Economical production of samples and very short runs - Has no wasted ink/dye - Millions of colors - Strict respect between sampling and industrial runs - Applicable to all types of fabric - Generate new design styles impossible from conventional printing - Increase numbers of niche products and unique designs - Increase demand for personalization to add value - No requirement for inventories	- Very expensive inks - Limited speed - Only economical for short runs

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