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Digital Inkjet Textile Printing

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SAVONIA UNIVERSITY OF APPLIED SCIENCES **THESIS**
Abstract

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Abstract

Digital inkjet textile printing is an emerging technology developed with the rise of the digital world. It offers a possibility to print high-resolution images with unlimited color selection on fabrics. Digital inkjet printing brings a revolutionary chance for the textile printing industry. The history of textile printing shows the law how new technology replaces the traditional way of printing. This indicates the future of digital inkjet textile printing is relatively positive.

Different from conventional screen printing, digital inkjet textile printing has its digitalized printing process which provides a more efficient sampling process. Though digital inkjet textile printing shows an obvious advantage to the textile industry, obstacles, due to high requirement of operation, limit the wide application of new technology at present. The ergonomics and features of digital textile machines need to be developed further to keep this new technology in current demanding position in the textile industry.

Through this thesis, a glance is taken at digital inkjet textile printing world. Not just knowledge but also understanding of this emerging technology in the textile printing industry is gained. Furthermore, digital inkjet textile printing offers a chance to meet changing market demand in textile printing industry by realizing mass customization and Just-in-time. This thesis opens a view for those who seek opportunities in the apparel industry.

Keywords
Digital inkjet textile printing, textile printing industry, digital inkjet printer

CONTENTS

1 INTRODUCTION

This thesis aims to become a step stone for those who are interested in digital inkjet textile printing. The twenty-first century is a generation for digitalization. Digital technology permeates into human activities. There is no exception when concerning textile printing industry which has its peculiar position in human history. Printed textiles have become one of the essentials for our daily life. Six main questions will be explored in the following chapters: what is digital inkjet textile printing? When has it been developed? Where has it been developed? Why digital inkjet textile printing should be developed? Who will devote to its development? How does a technology of inkjet textile printing work? Through the history of textile printing, the reader will get an overview of the textile printing industry. The regularity of textile printing development can be found through significant events. In a way, that helps people to understand better what is happening now within the textile printing industry.

Digital inkjet textile printing is destined to be one of the significant events for textile printing history because of its characteristics. Therefore, the definition of digital inkjet textile printing is discussed carefully by exploring its origins in Chapter 3 to bring out a deeper perspective. In Chapter 3, the reader will also get a preliminary understanding towards the principle of digital inkjet textile printing, such as the process of digital inkjet textile printing and the useful information relates to each step. Chapter 4 answers the question why digital inkjet textile printing is developed by comparing its time efficiency, cost efficiency, customer satisfaction and environmental impact with conventional textile printing. Chapter 5 gives two examples to present the application of digital inkjet textile printing: mass customization, and Just-In-Time. The reader can find the answer from this chapter about why digital inkjet textile printing is developed as well. This thesis provides a window to readers who want to take a glance at digital inkjet textile printing for it is a charismatic technology. This technology creates more space for designers to realize their fantastic dream on textiles.

2 OVERVIEW OF TEXTILE PRINTING

2.1 The Development of Textile Printing

2.1.1 Ancient Egypt

The ancient Egyptians started the decoration on fabrics thousands of years ago. They developed a complete process which includes four main steps to decorate fabrics during the Dynastic period. The first step was smearing. People spread the fabric with color paste and pressed the color paste into the fibers. The second step was indigo dyeing which was a complex vat process involving oxidation. The third step was adjective dyeing; mordant was added during the coloring process to fix the color. Alum was easily accessible as a mordant material for Egyptians at that time. The last step was dyeing twice; fabrics would represent a mixture color created by two times dyeing with a different color. The ancient Egyptians already knew how to remove the color from fabrics by putting them under the sun (Vogelang-Wood 2000). Egyptians practiced woodblock printing on textiles over 2000 years ago (Chamberlain 1978). The size of the wooden blocks was limited by the size of the tree. That lead to the size of the pattern was printed on fabrics at that time were about 25 centimeters by 30 centimeters. (Carden 2016.)

2.1.2 Eighteenth and Nineteenth Centuries

2.1.2.1 Woodblock and Copperplate Printing

Woodblock printing was used for textile from the beginning. In the fifteenth century, copperplate printing began with printing on paper. Until 1752, copperplate started to be used in textile printing called Calico Printing in Ireland. After then it became popular in the textile printing industry. But when practitioners tried to use copperplate to displace woodblocks, the first challenge that they needed to face was the different requirement of the viscosity of the ink used in woodblock and copperplate printing. The woodblock was made as a relief surface, and the woodblock with color paste was stamped down onto the textiles to print pattern. Therefore, the thicker paste was needed for staying on a wooden block. The copperplate was etched. Different with woodblock printing, Copperplate was laid out flat and ink was placed on the top of the engraved surface. Fabrics were pressed tightly together with the copperplate by mangle. Then the liquid ink was transferred from the metal plate to the textiles to create a pattern. The thinner ink was needed to fill the

nick. Thus, starch was developed as a substance and process to fulfill the requirement of different consistency of the ink. (Chamberlain 1978; Cooper-Hewitt Museum 1987.)

2.1.2.2 Roller Printing

In the eighteenth century, woodblock and copperplate printing continually occupied the most important role of European textile printing industry. Thomas Bell developed roller printing process and owned the patent in 1783. The newer technology brought impact on conventional printing. The usage of woodblock and copperplate printing was decreased. Roller printing created a continuous system where dye was picked up by a trough. It produced the cyclical pattern. The invention of roller printing prevented textile printing from the restriction of the re-register problem in woodblock or copperplate printing. Since then, textiles could be printed continuously. (Carden 2016.)

2.1.2.3 Dyes

In eighteenth and nineteenth centuries, textiles were brought by trade road called Silk Route which had a good reputation in Europe (Sardar 2000). The European producers tried to imitate eastern style pattern coming from Indiennes or chintz design. Though they had excellent skills to print the pattern to have similar shape and color as the textiles printed in the east. But the color fastness, color fastness to light and water of these imitated textiles were unsatisfactory compared with the genuine ones. Until merchants brought technical details about how oxidation, indigo vat dyeing, and white resist dyeing were used on the east coast of India, the European producers could improve their competitiveness against original chintz textiles producer in India. (Carden 2016.)

2.1.2.4 Synthesized Colorants

In 1856, Perkin invented the first completely synthesized colorants (North 1969). Synthesized colorants were brighter than natural colorants, and had the ability to create more usable hue. Still, they could not replace natural colorants at that time. The reason was that synthesized colorants were technically immature; the color was easy to fade. Practitioners at that time preferred natural colorants (Parry 2009). With the further

development of synthesized colorants, the use of conventional natural colorants in the textile industry was shaken. More and more usable synthesized colorants were available for practitioners. They had practiced how to use natural colorants proficiently. Their knowledge and skills of natural colorants surpassed synthesized colorants significantly. (Carden 2016.) All those phenomena limited the application of new technology during that time.

2.1.3 Nineteenth Century

2.1.3.1 Screen Printing

By the 1930s, the invention of flatbed screen-printing promoted textile printing industry to a new level. Screen-printing used opposite way to woodblock and copperplate printing printed pattern on fabrics (Carden 2016). Screen-printing was stencil printing. The principle was to use certain pressure to press the mash through ink hole in the flat. Then the image formed by ink hole could be transferred to the substrate (fabrics). The screen used in screen-printing was made by silk fabrics, synthetic fiber fabrics, or wire mesh stretched in the net frame. There were two methods to create ink hole on the screen. One was hand-painted film method; another was a photochemical plate-making method. The graphic part of the mesh hole was through-hole so that the mash can be pressed through. The hole was blocked rather than the graphic part of the mesh.

2.1.3.2 Rotary Screen Printing

In the 1950s, screen-printing was applied to roller printing. So far, printed textiles with maximum twelve different colors could be produced. In the late twentieth century, the rotary screen-printing machine replaced most of the roller printing machines. (Carden 2016.)

2.1.3.3 Transfer Printing

Transfer printing was developed during the 1980s (Carden 2016). Transfer printing on the garment was normally divided into thermal transfer printing and sublimation transfer printing. Thermal transfer printing was commonly used in the cotton product; the

sublimation transfer printing was used in polyester materials. The principle of transfer printing was first printed pattern with the dispersion of dyes and ink on the special paper called transfer paper. Then the transfer paper with a printed pattern would be affixed to the unprinted face of fabrics, and was passed through the thermal transfer machine. The high temperature made the dye on the transfer paper was sublimated and transferred to the fabrics completely. The invention of transfer printing simplified the printing process compared to screen-printing or rotary screen-printing. It allowed more complex digital image be printed on textiles.

2.1.3.4 Digital Color Separation System

At the end of the 1980s, a computer program came up at Dundee University. The color of digital images created by simple programming could be separated by a dot matrix printer using RGB (red, green, blue) channels through the computer program. The impact of this technology on textile printing industry was that people could use hand-printing methods to print digital images on textiles because the color of those pictures could be separated since then. (Carden 2016.)

2.1.3.5 Digital Inkjet Printing

In the 1990s, the number of people who were interested at Digital Inkjet Printing rose rapidly (Moser 2003). One significant event of digital textile printing history happened in ITMA (the largest international textile and garment technology exhibition), 1995. Stork revealed a technology demonstration of a digital textile coupon printer which was launched by the European subsidized project (BriteEuram) at the exhibition (Notermans 2012; Fang, Digital ink jet printing technology 2006.)

2.1.4 Conclusion

The replacement between new and old always acts in a similar way. Over a hundred year ago, people tended to keep traditional methods of textile production. Just like currently new textile digital machine manufacturers meet bottlenecks because traditional printing methods have been lasting for a long time, and still have its competitive strength. But as long as people do not give up the development of new technology and new solution, the old method will be replaced gradually.

2.2 Statistics

The worldwide production of printed textiles is over 27 billion square meters per year. Conventional textile printing like rotary screen printing dominates the field. The volume of digital printer printed textiles is about 500 million square meters per year, accounting for 1.8% of the total textile printing output. The number of the digital textile printer is about 5000, mainly located in Europe. Europe has the largest demand for digital printing products, and produces the largest amount of digitally printed textiles. Many European digital textile printing factories have 20 to 30 digital printers mainly distributed in Italy and Spain. The production of digital printing products in the European region is accounted for about 30% of its total output of printed products. Also, European textile printing factories put most of the investment on digital textile printing instead of conventional screen textile printing. (Fang 2011.)

3 PRINCIPLE OF DIGITAL INKJET TEXTILE PRINTING

3.1 The Definition of Digital Inkjet Textile Printing

Digital Textile Printing is to use digital technology for printing pattern on textiles. Digital Textile Printing technology is developed with the continuous improvement of computer technology and gradually formed as one of the high-tech products which combine machinery and computer electronic information technology. The emergence and continuous improvement of Digital Textile Printing technology have brought a new concept to the textile printing and dyeing industry. Its advanced production principles and means lead textile printing and dyeing industry to unprecedented opportunities for development.

Only the origins of textile printing were referred in Chapter 2. While people want to define what is Digital Textile Printing, the origins of it cannot also be missed. Digital printing machine works the same as an inkjet printer. Inkjet printing was a new printing method based on the principle of fine fluid splitting into droplets. This inkjet printing technology can be traced back to the nineteenth century. In 1867, the first patent for an inkjet printing system was given to Lord Kelvin (Sir John William Thomson) (Cahill 2006). Later, Lord Rayleigh (Sir John William Strutt) described the mechanism of one bundle of fluids split up into droplets in 1878. (Cahill 2006; Fang, Digital ink jet printing technology 2006.)

In the early 1960s, Sweet came from Stanford University split the tiny ink stream into uniform droplets with a bunch of pressure waves. Those droplets were selectively applied with charge. The charged ink droplets would be deflected into the ink collector, while they went through an electric field. And the uncharged ink droplets flew directly onto the recording medium to form an image. This process was called continuous ink jet (CIJ). In the 1970s, an American company called IBM put many efforts to study the application of CIJ technology in computer inkjet printer. (Fang 2006.)

In the late 1970s, the first ever drop on demand (DOD) ink jet print method was introduced. This kind of devices printed ink only by the usage of the ink droplets' image application on the medium. Many DOD inkjet systems were developed and commercialized from the 1970s to the 1980s. Such as the Siemens PT-80 series printers all used DOD inkjet technology. (Cahill 2006; Fang, Digital ink jet printing technology 2006.)

In 1979, Canon invented a bubble-jet technology that sprays ink from the nozzle by using the production and disappearance of water vapor bubbles on the surface of a tiny heater

near the nozzle. In the same period, Hewlett-Packard company in America independently invented a similar inkjet technology called Think jet. That was the invention of thermal inkjet technology. Currently, thermal inkjet technology is the cheapest ink technology and widely used in medium- and low-end inkjet printers.

Digital inkjet textile printing was developed based on inkjet printing technology. It was commonly believed that digital inkjet technology for fabrics printing originated in American company called Milliken and Austrian company called Zimmer during the 1960s and the 1970s (Carden 2016; Fang 2006). The Millitron system developed by Milliken and the Chromojet system developed by Zimmer were precisely controlled by the computer, and the inkjet printing was carried out by using a valve to deflect the ink droplets. There was a low printing accuracy problem. The resolution at that time was only nine to eighteen dpi (dots per inch). (Fang 2006.) Therefore, it was used mainly for printing fabrics with low accuracy demand, such as carpet printing. So far, most of the printed carpets in the world are produced by inkjet printing method. (Carden 2016; Fang, Digital ink jet printing technology 2006.)

In the 1980s and 1990s, the office automation system became popular because of the rapid development of computer technology. At that time, the inkjet paper printing technology used in office got rapid promotion and application. This developed paper printing technology that was quickly ported to advertising and textile printing field. (Fang 2006.) In 1987, Gerber Scientific developed one digital inkjet printing system for billboard maker Metro Media Technologies (MMT). Since then, MMT became the largest supplier of grand digital printed billboards around the world. Competitors of MMT in the advertising market were racing to develop digital printing (Cahill 2006). The inkjet printers which were widely used in advertising field formed the prototype of many inkjet printers for textiles. Therefore, many present inkjet textile printer manufacturers were also the manufacturers of advertising inkjet printer. (Fang 2006.)

The development of digital printing caught the eyes of textile printing practitioners because of its accessibility to thousands of colors, ability to avoid contacting with fabric during printing, the unlimited size of images, and unlimited print runs (Keeling 1981). In the 21st century, digital inkjet textile printing has been further developed. So far, the concept of digital inkjet textile printing can be defined like this: it is a process which the digital form of required printed pattern will be entered first into the computer by scanner, digital camera, or other methods; then after the image software process the pattern will be printed directly onto the fabrics by sprayed ink through the computer-controlled digital inkjet printer. (Fang 2006.)

3.2 The Process of Digital Inkjet Textile Printing

FIGURE 1 below shows the stages of Digital Inkjet Textile Printing. It is initiated from designer's idea of the image. Then the concept of the image will be processed by digital technology into the computer. After the computer-aided design (CAD) system has edited and separated the color of the image, a specialized printing program called Rester Image Processor (RIP) controls inkjet printing system to spray ink (such as active, dispersed and acid dyes, and pigments) directly on a variety of fabrics. Fixing is the step for fixing the color on printed fabrics by steam. In this section, the discussion about the process of digital inkjet printing includes three stages (computer, inkjet printer, and printing) from the figure below.

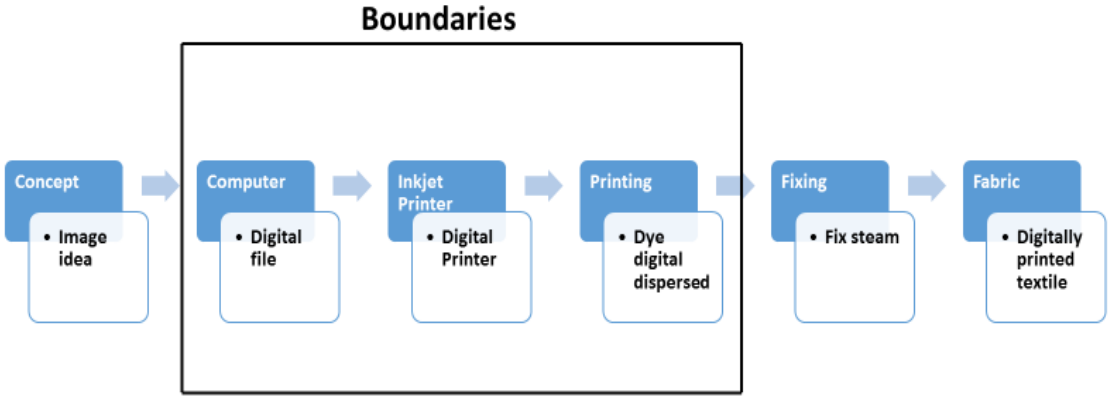

FIGURE 1. Stage of digital textile printing (Carden 2016).

3.2.1 Digital File

3.2.1.1 Digital Image Design

The digital technology has entered our daily life. The textile printing industry also followed the trend and adopted computer-aided design (CAD) system to aid pattern design and computer aided manufacturing (CAM) system to facilitate production. CAD-CAM system was used for traditional textile printing in the beginning. However, now it is more and more

needed for innovative textile printing with the development of digital inkjet printing. The design of printed pattern can be created on different kinds of drawing software. But the textile design has its own special requirements towards the digital image of the pattern. Therefore, practitioners are required to employ proprietary software which does not only fulfill the requirements of graphic design but also can be augmented with other features to build an integrated color management system (CMS). CMS aims to assist the realization of production's accuracy and reliability. (Dawson 2006b.) Different from conventional textile printing, reproduction of digitally printed textiles is relatively difficult. The accuracy and reliability of reproduction of screen-printing and rotary screen-printing can be ensured by saving formulation of color paste and screen previously used. The print result of a digital inkjet printer is easily affected by many factors, such as air humidity, air temperature, and printing speed. Therefore, an effective color management system is required.

TABLE 1 shows examples of different design software and its operating systems. Macintosh was the most popular operating system base. However, MS Windows XP and PC based system become more popular than Macintosh. Some of the design software can even demonstrate designed pattern on garment through 3D modeling features. It becomes possible for designers to promote their design by visual demonstration. (Dawson 2006b.)

TABLE 1. Some CAD systems suitable for textile print pattern editing (Dawson 2006b).

Company *(Website)*	Design system	Computer/system base
Aleph (Italy) *(http://www.alephteam.com)*	Smartcolor	MS Windows
B-Tree (Italy) *(http://www.btree.net)*	TreePaint	Macintosh/MacOS
DGS Dua Graphics (Italy) *(www.ceam-group.it/DuaGraphic)*	Matchprint II	PC/Linux
DP Innovations (USA) *(http://www.DPInnovations.com)*	StudioMaster	PC/MS Windows
Lectra (France) *(http://www.lectra.com)*	Primavision Print	PC/MS Windows
NedGraphics (Holland) *(http://www.nedgraphics.com)*	Vision Printing Studio	PC/MS Windows
SpeedStep (Germany) *(http://www.speedstep.de)*	ProPainter 2000	PC/MS Windows
Stork (Holland) *(http://stork.com)*	Image PC/BestImage	PC/MS Windows

3.2.1.2 Digital Color Management

As discussed in the previous section, there are obstacles caused by ambient that prevents the facility of the reproduction of digital inkjet textile printing. In this section, the basic reason for color proof problems during reproduction is studied. The difficulty to attain a result which can be continuously accepted by viewer is determined by the complex physical processes involved in perceiving (the observer's vision), capturing (digital image capture), displaying (computer monitor display) and reproducing (digital color printer) color varieties (Dawson 2006a).

Color management system (CMS) assist color data in transferring from image capture to the printing system. The color management system which is developed for textile printing has been further adapted into textile inkjet printing control software. TABLE 2 gives examples of CMEs at different sophisticated level. Most of the systems listed in Table 2 require users pick a suitable spectrophotometer for their own measurements. (Dawson 2006a.)

TABLE 2. Color management systems (Dawson 2006a).

Manufacturer *(Website: http:///)*	Product	Platform
Agfa *(www.agfa.com/graphics)*	ColorTune CMM	MacOS
Aleph *(www.alephteam.com)*	Newton	MS Windows
Chromix *(www.chromix.com)*	ColorValet	MS Windows/MacOS
ColorSavvy *(www.colorsavvy.com)*	SavvyProfile suite	MS Windows/MacOS
Color Solutions *(www.color.com)*	ColorBlind Prove-It	MacOS
Colorburst Systems *(www.colorburstip.com)*	Colorburst Pro	MS Windows
Colorvision/Datacolor *(www.colorcal.com)*	ProfilerPRO, DoctorPRO	MS Windows/MacOS
Ergosoft *(www.ergosoftus.com)*	TexPrint	MS Windows
Fujifilm *(www.colorprofiling.com)*	ColorKit profiler	MS Windows/MacOS
GretagMacbeth *(www.gretagmacbeth.com/il)*	NetProfiler, Profilemaker	MS Windows
Heidelberg *(www.heidelbergusa.com)*	Prinect Calibrator/Profiler	MS Windows
Kodak Polychrome *(www.kpgraphics.com)*	Matchprint	MacOS
Pantone *(www.pantone.com)*	ColorVision and ColorPlus	MS Windows/MacOS
X-rite/Monaco *(www.xrite.com)*	MonacoEZcolor & Profiler	MS Windows/MacOS

Color Management System aims to provide a control system which can reliably and accurately transform the measurement of origin design color into output data. The output data can be displayed on a monitor or input to a printer, so that the presentation of the appearance of output is close to designer's input. FIGURE 2 below shows the involvements of the color data transpositions. (Dawson 2006a.)

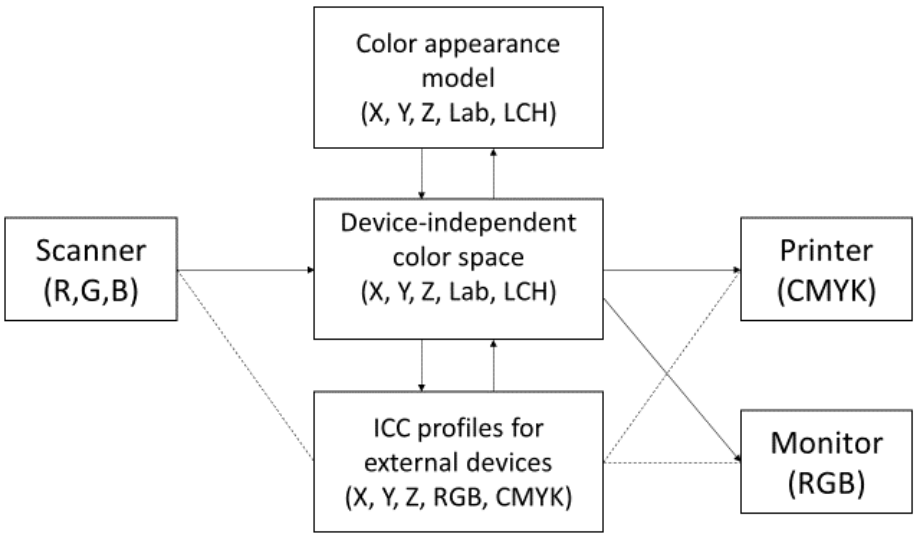

FIGURE 2. Summary of color data transpositions (Dawson 2006a).

Currently, the digital printer has been used for sampling and proofing digital design only especially for longer print runs. This means a digital printer prints sample for customers to proof, then the bulk production is done through the conventional textile printer. The print pastes used in screen printing or rotary screen printing contain completely different dyes. In such cases, it is important that the spectrophotometric data on every single color in design can be obtained in color management system. Therefore, CMS may provide a precise recipe prediction for conventional production. (Dawson 2006a.)

3.2.2 Digital Printer

In the twenty-first century, digital inkjet textile printing technology has been developed further rapidly. The number of inkjet printer manufacturers increased, and the performance of the printer has been improved. There are for example, DReAM printer made by an Italian company Reggiani, Artistri printer made by an American company DuPont, Amethyst printer made by a Dutch company Stork, and Mimaki printer made by a Japanese company.

3.2.2.1 DuPont Artistri 2020 Printer

The Artistri 2020 printing system is mainly used for commercially short-run textile printing. The machine is 1.8-meter wide (see FIGURE 3 below). It offers eight color channels for printing which are named cyan (C), yellow (Y), magenta (M), black (K), light cyan (lc), light magenta (lm), C1 and C2. There are three selections of printing resolutions: 360, 540 or 720 dots per inch. Print speeds can reach from 15 to 60 square meters per hour depending on the setting of resolution and other parameters (see TABLE 3). The printed textiles with highest quality and resolution take a longer time to print. The Seiko Printek piezo DOD printheads are utilized in the Artistri 2020 printers. Artistri Ink, Artistri Color Management System and Ichinose Toshin Kogyo developed this printer together for reaching the best print quality and performance. The printer is manufactured in Japan presently (Raymond 2006).

FIGURE 3. DuPont Artistri 2020 printer (Raymond 2006).

TABLE 3. Print speeds in relation to resolution (Raymond 2006).

Resolution	Print speed (square meters per hour)		
	High speed (draft)	Standard interlacing	Highest quality
360	66	45	23
540	44	30	15
720	33	22	11

3.2.2.2 DReAM Printer

The DReAM printing system can operate fabrics with maximum 1600 millimeters to 2200 millimeters wide. The size of the machine is 3 meters wide and 6 meters long (See FIGURE 4 below). It utilizes a roll-to-roll system to feed the textiles. It uses piezoelectric DOD printheads provided by Scitex Vision company. The printer is equipped with seven printheads. There are six colors available on each printhead. It can print textiles with 600 dots per inch real resolution and 150-190 square meters per hour printing speed. DReAM printer is developed by the collaboration of three companies, Reggiani, Scitex Vision, and Ciba Specialty Chemicals. (Caccia and Nespeca 2006.)

FIGURE 4. DReAM printer (Caccia and Nespeca 2006).

3.2.2.3 Mimaki's Tx Series Printer

The first Mimaki's Tx series printer was released in 1998. It adopts 720 dots per inch plotting resolution (Kobayashi 2006). The maximum printing speed is from 50 square meters to 150 square meters depending on machine type. The size of the machine is smaller than Artistri 2020 and DRaAM printer (see FIGURE 5 below).

FIGURE 5. Mimaki's Tx series printer (Mimaki n.d.).

3.2.3 Dye Digital Dispersed

Regarding digital inkjet printing, the image is formed by small color dots called resolution. Different fabrics have different requirements towards resolution. Generally, 180-360 dots per inch resolution offers satisfactory clear image. For 360-720 dots per inch resolution image, the printed substrate can present an exquisite pattern. But for textiles printed by a digital inkjet printer, the resolution of images is restricted by the yarn counts, density and specifications of different fabrics. Therefore, the sharpness of printed pattern is not in direct proportion with resolution. (Yang 2003.)

Still, the resolution is an important measurement for digital textile printing. The improvement of resolution is proofed by the improvement of injection frequency and positioning accuracy of the nozzle. Other than the requirement of high-precision nozzle control technology, the ink with high-purity, high-concentration, high-fastness and high-

stability are needed to match the nozzle technology to realize the practical value of digital inkjet textile printing.

3.2.3.1 Rester Image Processor (RIP)

Rester Image Processor (RIP) is the core of digital inkjet printer. Its basic task is to receive scanned digital images, separate and manage color. The most important task is to control inkjet system by digital technology. There are few suppliers around the world, such as Sophis, Stork, Ergosoft, Nedgraphis, DGS, AVA CAD/CAD. (Yang 2003.)

3.2.3.2 Print Head

The development process of digital inkjet textile printing technology can be represented by the continuous development of its nozzle in the print head. With the rapid development of digital inkjet technology in office (paper) and advertising (film) application, great progress in improving the accuracy of inkjet images has been made. Numbers of DOD inkjet nozzle have been invented, such as DOD Piezoelectric nozzle, DOD Thermal nozzle, and DOD Solenoid Valve nozzle. Only Zimmer company uses DOD Solenoid Valve nozzle to develop digital inkjet carpet printer. Konica, Canon and other companies have launched a digital inkjet textile printer with DOD Thermal nozzle. The patent of the nozzle is owned by few companies. For example, Canon and Hewlett-Packard own the patent of DOD Thermal nozzle. Most of patents of DOD Piezoelectric nozzle production are owned by Epson Corporation. (Yang 2003.)

3.2.3.3 Ink

The ink used in digital inkjet textile printing is mainly produced on water-based dye (active, dispersed and acid dyes) or pigments. Dye-based ink composed of four basic colors CMYK (cyan, magenta, yellow and black) plus 24 different kinds of special colors (such as golden, orange, red, blue) is widely used presently. (Yang 2003.)

The diameter of the nozzle is normally small, and the resolution requirement is high. That is why the viscosity, surface tension, purity, concentration, containing impurities (salt) of

the ink have a high demand. Different nozzles have different requirements relating to the above measurements. This means some digital inkjet textile printers are required to use a specified brand of ink to ensure the normal operation of the device. The cost of ink causes the high cost of digital inkjet textile printing. Ciba Specialty Chemicals, Canon and DuPont applied plenty of patents refer to the ink used in digital inkjet textile printing. (Yang 2003.) The ink recipe is the core secret. The ink used in the digital inkjet paper printing has been developed maturely. But the development of the ink used in digital inkjet textile printing is still at its initial stage. Although several world class large companies have launched some series of ink products, still, the quality of the ink needs to be improved to adapt different nozzles.

4 COMPARATION BETWEEN CONVENTIONAL TEXTILE PRINTING AND DIGITAL INKJET TEXTILE PRINTING

4.1 Time Efficiency

FIGURE 6 shows the process of conventional textile printing and digital inkjet textile printing. The textile printing production is initiated by a design concept. Before a design concept is put into a real production, proofing is an important link that manufacturers need to go through. Designers will first draw the pattern down by CAD software. For digital inkjet textile printing, the digital file can be input to the printer. Digital inkjet printer will print samples for a designer to proof directly. However, the digital file used in conventional textile printing needs to be edited first. The color needs to be separated to make sample screen. The sampling department will mix color paste to print samples after the screen has been prepared. After this process, samples will be compared with the original. If the pattern or colors require re-modifying, the process will be repeated. With the digital inkjet textile printing method, the image of the sample can be modified directly on the computer and then a new sample can be printed. That saves a lot of time. Due to screen making, color paste mixing, and other reasons, conventional textile printing takes longer sampling time than digital inkjet textile printing. That leads digital inkjet textile printing to have more advantages on short runs production. However, conventional textile printing has a significant advantage in mass production. A rotary screen printer can print over 1000 square meters per hour, and a commercial digital inkjet textile printer only print in the range of 2 to 150 square meters per hour currently.

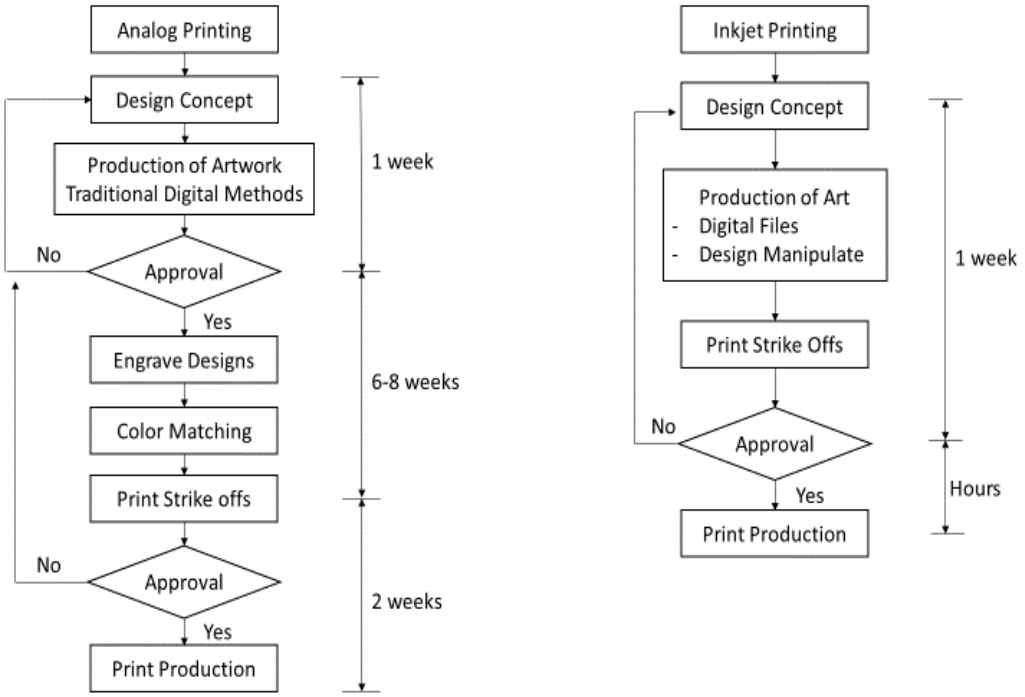

FIGURE 6. Conventional vs digital printing (Gupta 2001).

4.2 Cost Efficiency

Digital inkjet textile printing does not use screens like conventional screen printing. Therefore, all the costs related to screen engraving, paste making, strike-off, downtime and wastage do not exist. For short lengths of fabrics, the conventional textile printing process is not economical due to its high engraving cost, high wastage of fabric and ink cost, high labour cost, and cost of time spent on preparation stages. Especially, design sampling or proofing is a costly process in conventional textile printing. Nowadays, the length of print run for each design decreased and the amount of design increased to suit market requirement. Retailers need a small amount of variety. It raises the cost of conventional textile printing. For long lengths of fabrics, the application of digital inkjet textile printing still has its obstacles. Even though less labour is needed in digital inkjet textile printing process, it requires high-tech talents to operate the printer. The maintenance of digital inkjet textile printer is more difficult and costly than the conventional textile printer. The workplace where digital inkjet textile printer is located should be equipped with humidifier, air filter and conditioner to ensure the stability of printer. For example, new inkjet print head is expansive if the old one is broken due to an improper operation which can happen easily. High requirements of ink used in digital inkjet textile printing make the price higher than traditional color paste.

4.3 Customer Satisfaction

Patterns printed by a digital inkjet textile printer have better fineness than by the conventional textile printer. It is possible to have accuracy like photos which provide more possibilities for the designer. It is possible for a digital inkjet textile printer to print any number of colorways. All the technical data of digital inkjet textile printing images (including color match) are stored in the computer to ensure the consistency of printed sample and bulk production. Customers can access to the manufacturer through the internet. Digital inkjet textile printing brings the possibility to realize personalized e-commerce consumption of textile printing. Customers can send their own designs, personal data and requirements to the manufacturer via the internet. Products will be delivered to customers within a short period. But in bulk production, textiles printed by a conventional textile printer have more stable quality than digital inkjet printer.

4.4 Environmental Impact

Conventional textile printing needs to use a large amount of water to wash the screen during engraving process. Textiles, after printing, need to be washed and soaked to remove the floating color. The used water contains dyes; chemical additives cause a serious pollution problem. Conventional textile printing used more energy and water resources. The traditional textile printing industry is a high-polluted and high resource consumption industry. The unique advantage of digital inkjet textile printing has revolutionized the concept of the traditional textile printing industry. It solved the environmental pollution problems tradition of textile printing had, because the digital inkjet textile printing needs only dye instead of thickener and paste. There is no waste dye because it all goes onto the fabrics. That results in less polluted water. Digital methods used in textile printing transferred textile industry from the labour-intensive to the technology-intensive industry. It brings the promotion of textile industry to achieve clean production by applying digital DOD inkjet printing technology. The whole process excludes the emission of wasted ink and noise pollution.

5 APPLICATION OF DIGITAL INKJET TEXTILE PRINTING

5.1 Mass Customization

In the twenty-first century, consumers show a high preference for personalized products. People are not satisfied with the standardized service provided by mass production. Companies need to predict customers' demand and desire accurately to sustain market competitiveness. Digital inkjet textile printing is an emerging technology and has a large potential to fulfill market demand and impact company strategy. Mass customization can be realized by adapting digital inkjet printing technology in the textile printing industry, and influencing soft goods supply chain gradually. Digital inkjet textile printing method has brought an unprecedented personalized experience to textile printing and dyeing industry. Textiles printed by a digital inkjet printer are close to life with the combination of art and technology. It links design and production together, and achieves the feasibility of unlimited images printed on fabrics. Digital inkjet printing technology has potential to bring" WYSIWYG (what you see is what you get)" to the textile industry. In addition, business process and production process of textile printing can realize automation by applying digital inkjet textile printing. (Fralix 2006; Fang 2011.)

5.2 Just-in-time Printing

The textile printing industry is a high competitive industry. The risk consideration, timing and inventory management are critical for winning in the conventional textile printing process. The terminal demand of textile products is changing to "smaller quantities" and "shorter manufacturing cycles" gradually. Digital inkjet textile printing is the new method to meet market change. Wantuck (1989) explained Just-In-Time (JIT) is a production strategy to balance quality and productivity. He summarized JIT into seven principles: "produce exactly what customer demand, control waste, produce one-at-a-time, continuous improvement, respect people, zero contingency, provide long-term emphasis (Wantuck 1989)." JIT means delivered in a timely fashion and in direct response to market demands for the textile printing industry. Compared to conventional textile printing, digital inkjet textile printing has the flexibility to adjust printing length according to individual customer specification and changing market demand. It minimizes the impact of time and cost change over caused by new design or colorways by simplifying design stage (sampling, strike offs). Multiple printing works can be done through one digital inkjet textile printer. The printer can switch design, colorways and print types quickly. Since digital inkjet textile printing is still a developing technology offers the possibility of continuous

development by promoting technology and augmenting experiences. Digital inkjet textile printing technology utilizes individual creativity and opens the door for a unique design; it matches “respect people” in this way. By the decrease of waste and increase of production flexibility, some plans for dealing contingency can be avoided, such as excess inventory. Finally, the application of digital inkjet textile printing is a long-term strategy, and it provides “prints on demand” method. (King 2006; Fang 2011.)

In the past, manufacturers forecast the trend of textile design and customer’s demand first. Then they designed patterns, and printed in different fabrics as choices for retailers. Retailers selected products from limited options to put in the shop and wished their customer would like what they have selected. In nowadays, the application of JIT in that supply chain turns manufacturing driven economy to a demand driven economy. The development of digitization becomes a paramount factor to realize “prints on demand” principle. (Fang 2011.)

6 CONCLUSION

Digital inkjet textile printing is an emerging technology integrated with computer science, precision machinery, optic-mechanical-electric technology. In the 1950s, the invention of screen textile printing was a milestone in the textile printing industry. Later, textile printing was promoted by the application of Computer Aid Design (CAD) and Computer Aid Manufacturing (CAM) technology. A digital inkjet textile printer was developed after it. Practitioners even forecast that digital inkjet textile printing will bring a significant revolution to the textile printing industry. However, new technology will never replace the traditional technology overnight. Digital inkjet textile printing is still in the process to grow. People are excited about the facility which can print unlimited images on fabrics. It is true that digital inkjet textile printing can print thousands of colors with photos' resolution. However, there are problems that have come up during digital inkjet textile bulk production in practice. For example, the edge of fabrics is easily getting curly, the print head is difficult to maintain, extra ink droplets destroy the printed image, etc. The high requirements for operation environment, and operator's professionality also limited the wide application of this emerging technology currently. Now people know more and more about the benefits of new and high technology, it increases their awareness to install digital inkjet textile printer and put effort to develop it. All the obstacles in the application of digital inkjet textile printing will be removed when related technology is further developed. The ergonomics and features of digital textile machines need to be developed further to keep this new technology in current demanding position in the textile industry. One here to keep outlook on this emerging technology to see what kind of change it will make to our life!

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