Issues Impacting the Design and Development of an Ink Jet Printer for Textiles*

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Abstract

Unlike paper printing technology, which has advanced rapidly in pace with business and information systems, modern textile printing methods have changed little in the past four decades. This paper explores the application of current ink jet printing technology to textiles and discusses the requirements of an ink jet printer suitable for textile printing.

The primary motivations for adapting modern paper printing methods to textiles are achieve print on demand capability, enable economical short runs, and to enhance textile print design capabilities. Demand activated and just in time manufacturing requirements are pushing the textile industry to embrace more responsive printing methods. Modern paper printing technologies can be adapted to printing on textiles if a number of issues are addressed and resolved.

Significant issues include drop generation technologies, fluid handling, fluid properties, dye chemistry, output formats, web handling, throughput and data rates, effective resolution, image manipulation, and color correction. Many of these issues have been studied for application to paper printing and some previous work can be adapted to textile printing. Areas where textile and paper printing requirements differ significantly will require development of new methodologies and technologies.

Introduction

The textile industry, like many other industries, is changing to respond to consumer requirements for fast, customized products. Real time point-of-sale information is allowing retailers to more accurately gauge consumer desires and place smaller orders at more frequent intervals. This change to a demand activated manufacturing environment is pushing the textile industry to respond with very short lead times.

The ability to manufacture printed textiles with short lead times is inhibited by the printing process. In 1992 the world wide textile print production was estimated at 19.5 billion linear meters and the 1995 production predicted to be almost 21 billion[1]. Of those nearly 20 billion meters, between 75 and 78%[1,2] were printed using rotary or flat screen printing technologies. The screen printing process by its very nature is incompatible with short lead times. The typical process of designing a new pattern, manufacturing screens, printing a sample run, and then entering production requires between four and sixteen weeks. The cost of entering production requires minimum production print runs of two to three thousand yards. Once screens are available the time required to change over a screen printing machine for a new run of three thousand yards only allows for a machine utilization of sixty-six percent[2].

Taking a cue from the paper printing industry, where print on demand capability presently exists, the textile industry is investigating technologies that would provide similar capabilities for printing on textiles. The two primary technologies being investigated for on demand printing of textiles are ink jet and xerography[1,2,3,4,5]. Investigation into ink jet printing for textiles has been ongoing for over ten years and is presently being attempted by major players in both the paper and textile printing industries[2,4]. Given the potential economic benefit of on demand textile printing and the maturity of paper printing technology one may wonder why on demand textile printing capability does not presently exist. There are many technical issues that will have to be addressed before an on demand textile printer can be brought to market. In particular, ink jet printing of textiles will require investigation and development of appropriate drop generators, colorants, cloth handlers, and image processing techniques.

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Drop Generation

Ink jet drop generating technology is usually classified as either continuous or drop on demand (DOD). Continuous drop generators produce a continuous stream of drops that are either allowed to strike the print media and produce a mark or are diverted to a catch trough and are recycled back to the main fluid reservoir, Figure 1.

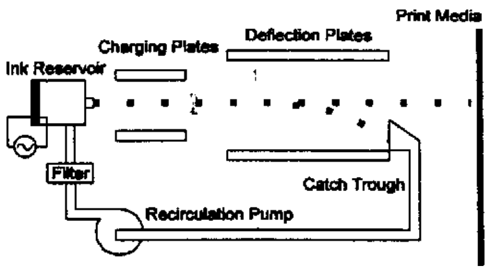

Figure 1. Continuous Ink Jet

Continuous ink jet drops are typically generated by modulating a pressurized fluid stream with a piezoelectric transducer. The drop rates of continuous ink jets can reach as high as one mega-hertz, allowing for very high print rates. A disadvantage of continuous ink jets is that drops are being produced even when none are required to print. The continuous exposure of the ink to the environment changes the ink properties through evaporation and exposes the ink to dirt and contaminates. The recycled ink must be filtered and the fluid properties monitored to insure continued jettability. Another, complication associated with continuous ink jet is the deflection of the drops. Both air jet and electrostatic charge deflectors have been implemented.

Drop on demand drop generators produce a drop only when commanded by the controlling electronics to produce a mark on the print media. Advantages of DOD ink jets over continuous ink jets are simpler fluid handling, since recirculation systems are not required, simpler drive electronics compared to charge and deflection systems, and reduced exposure of the ink to the environment. The major disadvantage of DOD drop generators is the low drop rate, less than ten kilohertz and typically between three and five kilohertz. DOD ink jets rely on surface tension and capillary action to refill the firing chambers after each drop. Drop rate is limited primarily by fluid dynamics of refilling.

DOD drops are typically generated by either piezoelectric or thermal energization. Mechanical and surface acoustic wave energization have been proposed but have not yet seen widespread use. Piezoelectic DOD drop generators rely on bulk motion of the piezo elements to energize the fluid and produce a drop. The piezoelectric material is activated by applying an electric field across the material. The electric field is typically applied by charging electrodes plated to opposing sides of the piezo material, Figure 2.

Typically one of the electrodes is in contact with the ink and must be of an appropriate material or coated to prevent degradation by the ink. Thermal DOD drop generators rely on boiling of the fluid in the channel to energize the fluid and produce a drop, Figure 3.

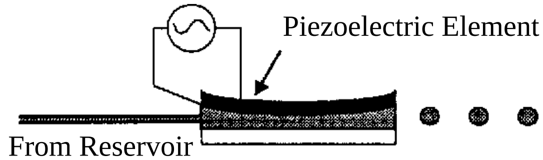

Figure 2. Piezoelectric Drop Generator

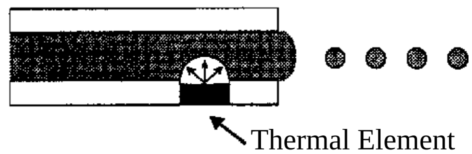

Figure 3. Thermal Drop Generator

Severe temperatures and pressures are generated as the fluid is flash heated and as the bubbles produced by the boiling collapse. The cavitation pressure and thermal cycling significantly reduce the life of the thermal drop generator. Where piezoelectric DOD drop generators have an expected life of one to ten billion drops, thermal DOD drop generators have an expected life of ten to one hundred million drops[6].

To achieve acceptable print rates large numbers of drop generators are required. A drop generator with a small footprint is required. Piezoelectric drop generators are much larger than thermal drop generators with equivalent nozzle counts. Thermal drop generators, which are produced by methods similar to semiconductor manufacturing, have begun to incorporate portions of the driving electronics into the nozzle substrate[7] further decreasing the nozzle footprint.

Fluid Handling

Continuous ink jet printers pressurize the ink and eject it at the printhead in a continuous stream. The unused potion of the stream is recycled back to the reservoir. The ink handling system must pressurize the jetted ink and capture and filter the unused ink. Drop on demand ink jet printers rely on the physical properties of the ink to keep the drop generators primed. This method is only effective over a small pressure range, typically a few tenths of a psi. The ink handling system must maintain the reservoir pressure within the proper window for the fluid properties to be effective.

Fluid Properties

Both continuous and drop on demand drop generators require the fluid properties to remain within a small range to insure jettability and compatibility with the printing hardware. Physical properties, such as viscosity and surface tension, as well as chemical properties, such as pH, solubility, and evaporation, must be controlled. Variations in fluid properties effect the consistency of the drops generated and result in satellites, variations in drop sizes, and variations in nozzle exit velocities[8]. Variations in drop size affect cloth saturation and resulting color. Variations in exit velocity affect print resolution by limiting the accuracy of the drop placement[9].

Dye Chemistry

In order to produce an ink jet printed textile to compete with a screen printed textile, the finished product will need to be of comparable or better quality. The printer and printing fluid will need to produce a permanent coloration of the textile with comparable fastness, durability, and hand. Previous textile ink jet sampling machines have not succeeded in doing so. Previous machines have concentrated on fluid properties for jettability not for textile dying. Significant effort has been applied to the development of dyes and inks for ink jet printing of paper. Multiple patents have been awarded for various inks and ink delivery systems[10].

Over half of the textiles printed world wide are pigment printed, with colorants being held to the fabric by a resin binder. The popularity of pigment printing stems from the lack of a required post treatment. Reactive dyes typically require steaming or other fixing process. An ideal on demand printer would print with either pigments or dyes.

Output Formats and Web Handling

Textiles are produced in standard widths from forty-five to one hundred twenty inches, most commonly between sixty to seventy four inches. By far the most popular textiles printed are cotton and cotton-poly blends, which make up well over half of the market[1]. Textile stretch can range from very little for felts and tight wovens to extreme for knits. If the printer operates via a raster method similar to current paper technology, the textile will be required to increment under the printhead with intermittent motion. Alignment must be kept in the presence of dynamics of starting and stopping a flexible material.

Effective Resolution

A typical screen printer has a resolution of fifty lines per inch. To produce the equivalent resolution on a dot matrix printer, a printer resolution of one hundred drops per inch (dpi) would be required. To expand beyond the present textile norm of spot color into continuous tone color, a minimum resolution of three hundred dpi would be required. Higher printer resolutions contribute to tonal resolution rather than spatial resolution or image clarity, especially given the wicking and bleed characteristics of cloth and the range of weight and density of available weaves.

Throughput and Data Rates

Rotary screen textile printers are capable of rates up to fifty meters per minute or thirty-two inches per second. A typical operating speed would be closer to ten inches per second or less. A one hundred dpi printer printing at ten inches per second over a sixty inch width using four colors would require a sustained data rate of twenty-four megabits per second. If the resolution were increased to three hundred dpi, the required data rate would increase to two hundred and sixteen megabits per second. If a drop on demand drop generator capable of generating ten thousand drops per second were available, it would require twenty-four hundred drop generators at one hundred dpi or twenty-one point six thousand at three hundred dpi. At one hundred dpi there are ten thousand drops per square inch. If four drops are required in each pixel for color or cloth saturation the total number of drops per square inch rises to forty thousand. If the resolution is raised to three hundred dpi, the total number of drops per square inch is three hundred and sixty thousand. To print three thousand linear yards of sixty inch wide cloth, there are almost two hundred and sixty billion drops at one hundred dpi and over two point three trillion drops, at three hundred dpi. If a drop generator has a life of ten million to ten billion drops then between twenty-six and two hundred and thirty thousand drop generators would be required, Table 1. This does not allow for any redundancy and assumes a constant failure rate.

Table 1. Drop Generators Required to Print 3000 Yds at 60" Width with 4 Drops per Pixel

dpi	100		300	
drop life	10^7	10^{10}	10^7	10^{10}
total drops	259 billion		2.33 trillion	
total required	25,920	26	233,280	234

Image Manipulation

Most image design and layout for textiles occurs using custom software developed specifically to meet the needs of the textile designer. Spot color, palette reduction, and step and repeat are integral parts of the design process. Typically the textile print designer works with a very small color palette since each color in the image requires a separate physical screen to reproduce. Textile print images typically have very little color depth or tonal variations. The designer of output for paper more often works with a CMYK process color space. This allows a large range of colors, including variations in color depth and tone, to be simulated while only using four distinct colorants. The disadvantage of the CMYK process color space is the very limited ability to reproduce deep rich colors that are easily produced with the custom mixed colors used in screen printing. An ink jet printer for textiles should have the capability to print with custom mixed spot color and with CMYK process colors. Design software to allow designing in either color space, spot or process, will be essential. Design software for ink jet textile printing should be similar in use to traditional textile design software to ease the transition from the tradition textile print design process but must have the capability to extend into the process color design arena to allow migration to or inclusion of process color in the design.

Color Correction

Designing prints for textiles using conventional four color process color design tools will pose a significant challenge. Variations in the patterns and surface structure of different weaves affect the tone, hue, and effective resolution of the image. As textile print designs begin to exploit the tone and hue variations available with process color, standards will be required to provide compensation for print media. The standard method of optically mixing colors on paper will be challenged by open weave textiles. Open weaves allow the background color to show through the print and allows for less positions to place drops for color mixing[11].

Moiré patterns, which result from slight alignment difference in linear patterns in a print, are a significant problem with printing on textiles. Many textiles have a strong regular repeating surface structure due to the weave of the individual fibers. Applying prints with strong linear elements run the risk of aligning those elements with the weave and producing unwanted moirés.

Conclusions

There is a demonstrated need and desire within the textile industry to have print on demand capability. Examining paper printing print on demand systems provides clues as to how a textile print on demand system might be implemented. Significant issues to be addressed in a print on demand textile printer include drop generating devices, fluid physical properties, fluid chemical properties, dye chemistry, selection of output formats, handling of flexible webs with intermittent motion, drop generator longevity, drop rate, image processing for spot and process color, and color correction for process color on textiles. Many of these topics have been studied in detail for paper printing and portions of the technologies developed can be applied to textile printing.

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