Thermal Ink Jet Printing of Textiles*

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Abstract

The flexibility and performance of ink jet technology as used for paper printing has long been a goal for textile printing. In the past there have been many attempts to develop a commercially viable ink jet textile printer. Due to technology limitations and market expectations none of these early implementations have enjoyed significant market placement. Advancements in ink jet printing technology and changes in the textile printing market combine to make ink jet printing of textiles more feasible and attractive than ever before.

We have investigated ink jet printing for textiles and have implemented a prototype full width ink jet textile printer. This paper discusses some of the paths chosen in the development process and describes the results of our experimentation.

Introduction

Ink jet printing of textiles has been a subject of research for some time [1,2,3,4,5,6,7]. Over the years there have been many attempts to develop a commercial ink jet printer for textiles. Due to technology limitations and market expectations none of these early implementations have enjoyed significant market placement. Advancements in ink jet printing technology and changes in the textile printing market are combining to make ink jet printing of textiles more feasible and attractive than ever before. We have investigated ink jet printing of textiles and have implemented a prototype full width, seventy two inches, ink jet textile printer. This paper discusses some of the paths chosen in the development process and describes the results of our experimentation. Also described is our prototype printer and a discussion of our results.

Ink jet printing depends on the successful integration of many dissimilar technologies. Drop generation, web handling, colorant chemistry, image processing, electro-mechanics, and more. The ink jet printing problem has been well studied and many successful commercial implementations exist for paper printing. Ink jet printing for textiles relies on many of the same technologies and commercially available paper printing technology can be adapted to ink jet printing of textiles if appropriate modifications are introduced.

Textile Printing Market [1]

The textile printing industry prints approximately twenty billion lineal meters of textiles each year. The three largest suppliers of printed textiles are the Far East at forty seven percent, North America at thirteen percent, and Western Europe at twelve percent. Rotary and flat bed screen printing account for almost ninety percent of all printing. The average width for rotary and flat bed printed textiles is sixty one and fifty four inches. The average number of colors in a screen printed textile is seven. One hundred percent cotton substrates account for approxi-mately forty five percent of the market, cotton polyester blends twenty percent, viscose thirteen percent, and polyesters twelve percent. Woven substrates account for nearly ninety percent of the market, knits almost ten percent, and others the small remaining fraction.

The average run length for rotary printers has fallen from forty five hundred meters in nineteen eighty nine to

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less than thirty five hundred meters in nineteen ninety four. Personal correspondence with commercial screen printers indicate run lengths are being compressed even further and are approaching the point where rotary screen printing will no longer be cost effective. The average run length for flat bed printers has fallen from twenty three hundred meters in nineteen eighty nine to less than seventeen hundred meters in nineteen ninety four. As run length shrinks then down time for screen change over becomes an increasing fraction of potential machine utilization.

Pigment printing accounts for fifty percent of the market, reactive dyes twenty seven percent, dispersed dyes fourteen percent, and vat dyes less than ten percent.

The world wide average printing seconds and rejects is almost eight percent or one point six billion meters. Primary causes of rejects in decreasing order are cloth faults, startup losses, repeat faults, paste faults, screen faults, smearing, paste shortage, maintenance, and fixation faults. Ink jet printing alleviates many of these faults as an inherent by product of the technology. Cloth faults are a function of the substrate and are unaffected by the printing technology. Startup losses, repeat faults, and smearing virtually disappear with ink jet printing. Screen faults will probably be replaced by printhead faults. Paste shortage faults will remain but will probably be lessened since ink jet printing relies on a smaller set of bulk dyes and the probability of running out of dye is less than when each print paste is custom mixed for a screen printing run. Maintenance and fixation faults are likely to remain independent of the printing technology. The three areas where ink jet printing can make a significant impact, startup losses, repeat faults, and smearing, total over five hundred and fifty million meters of reject cloth each year.

Given these market numbers we chose to concentrate on a printer capable of printing seventy two inch wide woven substrates. Due to limitations of ink jet's ability to jet pigments we chose to focus on reactive dyes for cellulosic materials, primarily cotton and silk.

Colorants

Ink jet printing technology has received significant attention as a possible successor to screen printing due to the ability of ink jet to deliver liquid dye to the substrate. The primary contender to ink jet for on-demand printing of textiles is thermal transfer. Thermal transfer has the significant advantage over ink jet in the area of reduced post processing but also has the undesirable quality of delivering a poor hand to the finished goods. In a market where quality and hand of the finished product is of primary concern dyed goods are clearly superior to transfer printed goods.

Unmodified commercial textile dyes suitable for printing of textile substrates are incompatible with ink jet printing technology. Properties such as viscosity, surface tension, drying, crusting, particulates, and chemical compatibility are issues. Commercial ink jet inks suitable for ink jet printing are chemically unsuited for dyeing of textile substrates. Commercially available textile dyes can be modified to be compatible with ink jet printing technology [7,8,9].

Drop Generation

Previous papers have described different types of ink jet drop generation technologies and discussed their relative merits [2,3,4,5,6]. We believe continuous ink jet to be too expensive and too bulky to meet the long term commercial needs of the textile printing industry. Continuous ink jet has the advantage of significantly higher drop rates compared to drop on demand ink jet. The higher drop rate potentially allows a much higher throughput per nozzle. Continuous ink jet has the disad-vantages of requiring conductive dyes, dye recirculation and filtering, and larger more expensive print heads compared to drop on demand ink jet.

We believe thermal ink jet provides significant potential for long term commercial and technological success. Low cost per nozzle and high nozzle density being the primary benefits. Future ink jet textile printers will require massive arrays to achieve competitive throughput. A drop delivery mechanism which is compact and cost effective is required.

Our prototype printer utilizes commercially available drop on demand thermal ink jet printheads. We have found the TIJ printheads to be very forgiving in terms of colorant fluid properties and to be resistant to chemical damage when jetting reactive and acid dyes. We have noticed susceptibility to minor crusting which interrupts drop generation [9].

Our prototype printer uses a raster printhead built up as an array from multiple TIJ printheads. We do not use the print cartridge normally associated with the printhead. We array the printheads to give the minimum footprint while allowing access to the printhead electrical connections. Fluid connections are through the back of the printhead and are machined into a custom printhead carrier.

High resolution requirements for paper printing are driving newer TIJ printheads to finer features and smaller drop sizes. Textile printing requirements are different than paper and finer drop sizes can be an advantage or disadvantage depending on the goals of the textile printer. Textile printing requires saturation of the substrate and usually requires much more dye per pixel compared to paper printing. Smaller drop sizes can be an advantage in that spot modulation can be performed resulting in greater tone gradation. The disadvantage of smaller drop sizes is that a larger number of drops are required per pixel to achieve substrate saturation. This is a problem due to the finite and relatively short lifespan of TIJ printheads.

We investigated TIJ printheads from Canon and Hewlett-Packard. We found both to be acceptable in terms of jetting modified textile dyes and to be of similar longevity. Our early experiments focused on the HP ThinkJet and DeskJet printheads. The ThinkJet printhead was available unmounted for OEM use, this allowed us to experiment with building large arrays of printheads. The ThinkJet has larger nozzles, drop volumes, and electrical connections than the DeskJet. The larger feature sizes of the ThinkJet makes it amenable to experimentation. The significant disadvantage of the ThinkJet compared to the DeskJet is the much lower nozzle to footprint ratio. The DeskJet imple-ments fifty two nozzles compared to the ThinkJet's twelve nozzles in a area approximately one quarter the size.

Repeated experiments with ThinkJet cartridges to measure drop size yielded results similar to those shown in Figure 1.

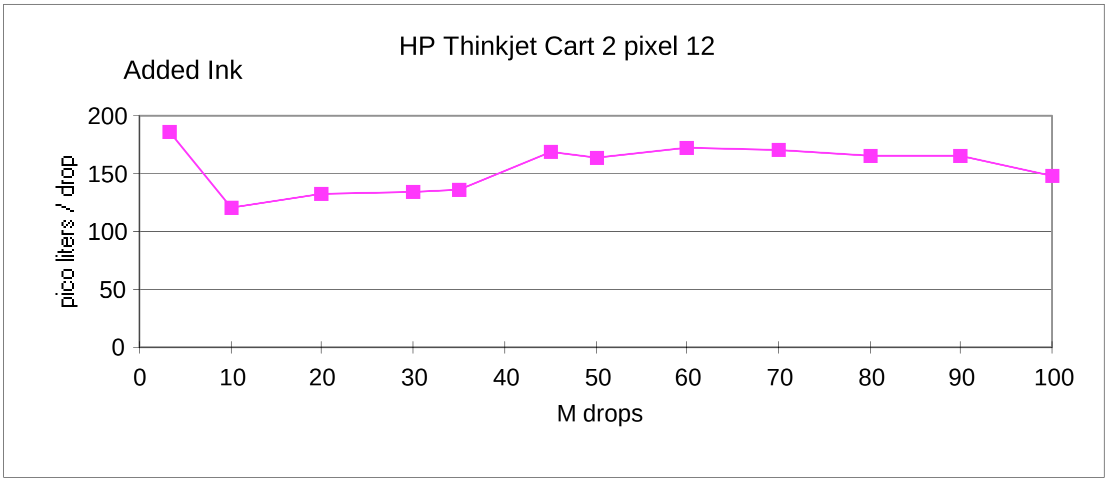

Figure 1 ThinkJet Drop Average Size

The average ThinkJet drop size was consistently around one hundred and sixty pico liters per drop. Printing on a range of materials from light weight silks to medium weight cottons required from one to eight drops to achieve acceptable substrate saturation. Noted during our experiments was that if a single nozzle was exercised to failure without exercising surrounding nozzles during the experiment then the nozzles immediately adjacent to the failed nozzle were negatively impacted. The nozzles adjacent to the failed nozzle would experience an increase in resistance of two to a thousand fold. We are unsure as to the cause of this failure. Exercising all nozzles in sequence during the experiment seems to alleviate the problem.

Fault Tolerance

In order to compete with the throughput of industrial screen printers ink jet printers will require a large number of nozzles. Depending on the desired throughput and ink jet cycle frequency the number of nozzles required could reach into the hundreds of thousands [6]. Given the large number of nozzles required the probability of an infant failure is high.

We have divided print failures into two classes; restartable failures and printhead failures. Restartable failures are those which can be corrected without requiring replacement printheads. Restartable failures are primarily caused by fluid flow interruptions. Restartable failures can usually be remediated by priming the printheads. Printhead failures are catastrophic failures of at least one nozzle which can only be corrected by replacement of the printhead. Once the fluid properties and fluid pressures are properly adjusted the printheads will usually print continuously to printhead failure.

Experimental results indicate the primary failure modes for TIJ printheads are resistor open failures and resistance increase failures. In our experiments the majority of failures, greater than ninety five percent, have been resistor open failures. Resistance increase failures manifest as an increase in printhead resistance from the nominal sixty five ohms for the ThinkJet to anywhere from ninety five ohms to millions of ohms.

The voltage drop across the printhead resistor can be monitored in real time to detect printhead failures. Restartable failures will not be detected but our experience indicates restartable failure are the minority.

Process color printing relies on a small set of dye colors which are mixed on the substrate to produce a wide range of colors. Ink jet printing of textiles will require a large number of drop generators per color to provide acceptable throughput. If a raster printhead is used the nozzles can be arrayed such that many nozzles of the same color dye pass over every printed pixel. If multiple nozzles pass over each pixel and all failed nozzles are identified then it is possible to map failed nozzles out of the printing sequence and shift the printing load to functioning nozzles. If failed nozzles are sensed in real time the worst case print failure is a single pixel failure. The worst case print failure only occurs if the failed nozzle is the last nozzle in the array to pass over the printed pixel.

Our experiments indicate that after infant failures the greater percentage of printheads print to an expected life within plus or minus ten percent. The HP ThinkJet heads yielded an average of one hundred sixteen million drops per nozzle with a high of one hundred thirty three million drops and a low of ninety seven million drops. Most of the nozzles failed between one hundred ten and one hundred twenty million drops. Remapping failed nozzles is probably most beneficial for increasing yield in large arrays by compensating for infant failures. As the nozzles reach end of life the probability of massive failure rises dramatically and the value of remapping nozzles is reduced. Remapping of failed nozzles can correct for single nozzle failures during the useful life of the printhead array. In practice single pixel failures are typically indiscernible when printing textiles. Wicking, dye spread, substrate surface features, and low resolution imagery used in textile printing provide effective concealment for many minor printing defects.

A less complicated first line of defense against nozzle failure can be provide by arraying the nozzles within the raster printhead as in Figure 2.

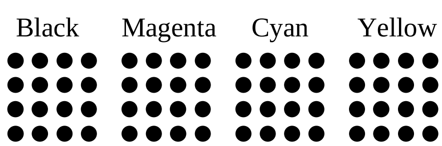

Figure 2 Print Nozzle Arrangement for Passive Fault Tolerance

As the printhead passes over the substrate multiple nozzles of each color pass over each pixel. If the substrate is heavy enough to require multiple drops of dye per pixel then the printing load can be assigned statically to multiple nozzles within a row. For example if a substrate requires four drops of dye per image pixel then each of the four nozzles in a row for that color can be assigned to place one drop of dye at the image pixel. As random nozzles fail other nozzles in the same row will still place some dye at the image pixel. The correct amount of dye will not be placed but we have found textiles to be very forgiving substrates to work with. In one experiment we printed with seventy percent failed nozzles using the passive fault tolerance scheme describe here with image quality only marginally worse than what might be expected from a draft mode. When printing with less than ten percent failed pixels using passive fault tolerance we found the quality of the print to be indiscernible compared to a fully functioning printhead array.

Electrical Interfaces

A major stumbling block we faced when implementing our prototype printer was bringing the electrical connections out from the printhead array. We considered wire bonding but for our prototype the cost and inflexibility were too great. We determined that anisotropic conducting film (ACF) is capable of handling the currents and voltages at the duty cycles used for typical TIJ printheads. A flexible mylar circuit board was manufactured and bonded to the printhead array with ACF. The mylar circuit had a fine pitch connector soldered to one end for connection to our custom electronics.

A variety of manufactures produce high power high voltage semiconductor arrays suitable for driving ink jet printheads. We found Allegro Microsystems Inc. [10] to have a large selection of suitable drivers.

Fluid Handling

We found the HP ThinkJet and DeskJet printheads will function with a large variation in fluid pressure. The HP printheads were able to print reliably with a head variation between positive one quarter inch and minus four point five inches. We found the greatest consistency in drop generation with a negative head between one and two inches.

Web Handling

Knits and elastomer fabrics account for less than ten percent of the printed textile market but typically have higher profit margins. Ink jet printing of textiles is still in the prototype stage and is significantly more expensive per printed yard than conventional screen printing. The ability to handle non rigid fabrics would make the cost of ink jet printing more attractive. Unfortunately handling non rigid fabrics is a significantly more difficult problem than handling rigid fabrics. Many rigid fabrics can be fed through a printer without any backing or support.

The problem of handling flexible webs has been around for a long time and a variety of solutions exist to transport webs rigidly under zero tension. Typical solutions involve backing the flexible web with a rigid web. Commercial screen printers use a sticky reinforced rubber belt which holds the cloth rigid while it is under the printing screens. A variety of flexible substrates have been backed with paper for feeding through standard wide format paper plotters.

Both of these solutions have significant drawbacks. Sticky rubber webs typically need some form of continuous surface maintenance. Sticky webs in commercial screen printers are washed and dried continuously to present a clean sticky surface to the incoming textile. Adapting the sticky web solution to a reasonably small form factor without the complexity of washing and drying may prove to be challenging. Kenebo and Togmin [11] of Japan have filed a US patent regarding the use of a sticky belt in a small form factor ink jet printer for textiles. Backing the fabric with paper works very well during the printing process. The fabric is held rigid and the printed goods can be rolled up immediately without fear of markoff. The downside of backed fabrics is the significant cost of converting the material.

Substrate Pre Treatment

The use of reactive dyes with cellulosic substrates requires the use of an activator to help progress the chemical reaction between the dye and the substrate [9]. When screen printing the activator is typically added to the print past. Longevity is a concern when using ink jet printing technology. Ink jet printheads have a finite lifespan which is relatively short when compared to the number of drops required to print a run of textiles. Given the limited lifespan of ink jet printheads it is desirable to use the printhead to only deliver the concentrated colorant to the substrate. Bulk chemicals which must be applied to all locations on the substrate can be applied prior to the printing process using an appropriate less expensive delivery mechanism.

In our prototype system we pre-pad the cloth with an alkaline solution using a hand sprayer and dry the cloth prior to introducing it into the printer. A mechanical sprayer could be used to apply the pre-pad solution during the printing process. The pre-padded textile needs to be dry before it is printed or significant wicking and blurring of the printed image occurs. An inline heater could be used to dry the substrate prior to printing. We have noted that non-uniform pre-padding produces artifacts in the printed image. A mechanical spraying and drying system could provide a more consistent pre-padding and drying of the substrate.

Effective resolution

Considering the wicking and bleed characteristics of cloth and the range of weight and density of available weaves the effective resolution when printing textiles is much smaller than what is possible for paper. A typical screen printer has a resolution of fifty lines per inch. To expand beyond the present textile norm of spot color into continuous tone color, a resolution of three hundred dpi is appropriate. Higher printer resolutions contribute to tonal resolution rather than spatial resolution or image clarity.

Smooth flat light weight substrates allow finer resolution images but require smaller drops and less dye to avoid excess wicking and image blurring. We have experimented with a variety of textile weaves and weights. We have focused on tight closed weave light weight fabrics which are optimal for image presentation. Heavy weight fabrics require more dye which results in greater dye spread. Coarse weave fabrics introduce visible artifacts into the image. The finest weaves we have experimented with have an effective upper resolution of two hundred dpi.

Software

Many commercially successful textile design packages are available. All of the packages we investigated have the ability to output the final image in a TIFF format. We chose to perform all image preprocessing off line and focus our efforts on developing the custom software to drive our prototype printer. After receiving the raster image the prototype software performs any necessary conversion to produce a four color binary image. The binary image is converted to printhead firing sequences and downloaded to the print head motion control and firing circuitry. The motion control system advances the printhead or web as necessary while monitoring for end of travel or home conditions. The printhead firing software loads the high power driver arrays and triggers a hardware timing circuit to generate a precise, short duration, firing pulse. The duration of the pulse is crystal controlled and programmable between 0.1 and 5000 microseconds. The magnitude of the pulse is set in the power supply hardware and is adjustable off line.

The four color planes are processed simultaneously. A number of image rows equal to the number of printer nozzles perpendicular to the print path are processed prior to printing each pass. At this stage the firing data could be remapped to account for any known faults in the printhead array.

Conclusions

Ink jet printing of textiles is a technology poised to revolutionize the textile printing industry. The textile printing industry is clamoring for an on demand printing solution for textiles. The largest section of the textile printing market is pigment printing of woven cotton fabrics. The second largest section is reactive dye printing of woven cotton. The textile printing industry loses almost one point six billion meters of cloth each year as seconds and rejects. Almost one third of the rejects can be prevented with ink jet printing technology. We believe future printers will require massive arrays of print nozzles to provide throughput competitive with screen printing technology. Passive and active fault tolerance can overcome infant failures and increase printhead array yields. Reliable handling of a continuous flexible web in a form suitable for on demand printing is an unsolved problem. Reactive textiles dyes require a chemical activator to be mixed with the dye to insure the dye reaction completes on the fabric. The activator can be mixed with the dye before it is delivered to the substrate or it can be applied to the substrate before the printing. If the activator is applied before printing then the substrate should be allowed to dry to prevent excessive wicking and blurring of the image. The wicking and surface features of textiles prevent high resolution output but hide almost all point defects in the printed output.

We have shown that thermal ink jet printing technology, when coupled with properly modified textile dyes, can produce output quality competitive with screen printed textiles. If a properly formulated textile dye is used then print heads developed for ink jet printing of paper can be used unmodified for printing textiles. Commercially available printers and plotters for paper can be modified to print on textiles if the textile substrate is bonded to a rigid web to carry it through the printer or if the textile is inherently rigid.

Other groups are investigating on demand ink jet printing of textiles. Major players in the textile and paper printing markets either have introduced or are poised to introduce near production rate ink jet textile printers. Canon has announced a one point six meter wide ink jet textile printer with a throughput of more than one meter per minute. Stork's TrueColor has been on the market for over ten years and has met with varying success. Scitex, the parent company of Iris Graphics, has also produced sample textiles printed with their proprietary continuous ink jet paper printing technology.

References

1. Stork1996 Marketing Study and personal correspondence
2. Tincher, F. Cook, W. Carr, B. Failor, Keynote Paper: Printing on Textile Substrates, IS&T 46th Annual Conference 1993, pp. 368-369.
3. L. Cook, Textile Printing Enters The Technological Revolution, Chemical Treatment and Finishing, March, 1995, pp. 73-79.
4. Ahmed, Jet Printing for Textiles, JSDC Vol 108, Oct 1992, pp. 422-424.
5. Provost, Ink Jet Printing on Textiles, Surface Coatings International, January 1994, pp. 36-41.
6. Hunting, R. Puffer, S. Derby, L. Loomie, Issues Impacting the Design and Development of an Ink Jet Printer for Textiles, IS&T Eleventh International Congress on Advances in Non-Impact Printing Technologies, pp. 374-377.
7. Smith and E. Simonson, Ink Jet Printing for Textiles, Computer Printing Vol. 19 No. 8, August 1987, pp. 23-29.
8. Provost, Recent Developments in Ink Jet Printing of Textiles with Reactive Dyes, IS&T Eleventh International Congress on Advances in Non-Impact Printing Technologies, pp. 378-382
9. Hunting, S. Derby, R. Puffer, L. Loomie, Textiles Dyes for Thermal Ink Jet Printing, IS&T Thirteenth International Conference on Digital Printing Technologies
10. Allegro MicroSystems, Inc., 115 Northeast Cutoff, Box 15036, Worcester, MA 01615
11. United States Patent 5,345,863, September 1993, Kanebo Ltd., Togmin Kogyo Co. Ltd., Tokyo Japan