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Digital Textile Printing: A Comprehensive Review of CAD, Color Management, and Digital Inkjet Technologies

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Abstract

This paper looks at the big changes happening in textile printing because of digital technology. It focuses on two main parts: the important role of Computer-Aided Design (CAD) software and the development of digital ink-jet printing (DIJP) machines over the last ten years. We explain how these two technologies are connected. The paper shows how the industry is moving away from old methods like screen printing to new, faster digital ways. We discuss how designs are made on computers, the problems of matching colours correctly, the different types of printing machines and inks, and how fabric must be prepared. The review also talks about the good and bad points of digital printing, like how it allows for custom orders and less waste, but is still slower and more expensive for big jobs. By putting together information from many studies, this paper gives a full picture of digital textile printing. It explains that while the technology is still growing, it is already changing how textiles are designed and made, leading to more personal, fast, and eco-friendly production.

Keywords: Digital Ink-Jet Printing, Textile Printing, CAD Software, Colour Management, Reactive Dyes, Piezoelectric Print Head, Fabric Pre-treatment.

1.INTRODUCTION

For a long time, most fabrics were printed using machines with physical screens. Rotary screen printing made about 58% of printed fabrics, and flat screen printing made 28% (Kan & Yuen, 2012). These methods are good for making thousands of metres of the same design. However, they are slow and expensive to set up because they need screens to be made for each colour in a design. Today's fashion world changes very fast. Companies need to make smaller amounts of many different designs and get them to stores quickly. The old screen-printing methods are not good for this new way of working (Dawson & Hawkyard, 2000).

Digital ink-jet printing (DIJP) is a new technology that solves these problems. Instead of using screens, it works like a computer printer, spraying tiny drops of ink directly onto fabric. This allows for quick changes between designs. The growth of this technology has been made possible by another important tool: Computer-Aided Design (CAD) software (Briggs-Goode, 2013). CAD software is where designs are created or turned into digital files that the printing machines can understand.

This review paper has two goals. First, it explains how CAD software acts as the "brain" of the digital printing process. Second, it reviews the past ten years of progress in the printing machines themselves—the hardware, the special inks, and how fabric must be treated. We will look at the benefits, the challenges that still exist, and what the future might hold.

From Old to New: Comparing Printing Methods

Comparison of Textile Printing Methods

Parameter	Flat Screen	Roller	Rotary Screen	Heat Transfer	Digital Ink-Jet
Squeegee	Moves back & forth	Not used	Rotates continuously	Not used	Not used
Fabric Movement	Step by step	Continuous	Continuous	Step or continuous	Step or continuous
Screen	Up & down	No screen	Rotary screen	No screen	No screen
Colour Supply	By hand	By hand	Automatic	No direct supply	Automatic
Design	Fine, no halftone	Very fine, halftone	Halftone, less fine	Many effects	Many effects
Fabrics	Not for knitted	Not for knitted	Knitted & woven	Mainly polyester	Woven fabrics
Sampling	Easy	Difficult	Difficult	Easy	Easy
Cost	Low	High	High	Varies	Low

Fig -1 Comparison of Different Printing Methods

Conventional Printing: This is a step-by-step process. First, a design is separated into its different colours. Then, a separate physical screen is made for each colour. Printing paste (a thick, coloured mixture) is prepared. A sample is printed to check. Finally, the big production run can start. This process takes weeks and costs a lot of money for screens and setup, especially for small orders (see Fig. 2 in Kan & Yuen, 2012).

Digital Ink-Jet Printing: This process is much simpler and almost all digital. A design is created or finished on a computer (CAD). This digital file is sent directly to the printer. The printer sprays the ink onto the fabric. There are no screens needed. This means there is no cost for making screens, no time wasted setting them up, and no limit to how many colours can be used.

Key Differences:

- No Contact: Digital printers don't touch the fabric, so designs don't get smudged.
- Flexibility: You can print a different design on every metre if you want. The repeat of a pattern can be any size.
- Set-up Time: Moving from one design to the next takes minutes, not days.
- Best For: Screen printing is still cheaper for very long runs (over 1000 metres). Digital printing is faster, better, and more economical for short runs, samples, and custom designs (Kan & Yuen, 2012).

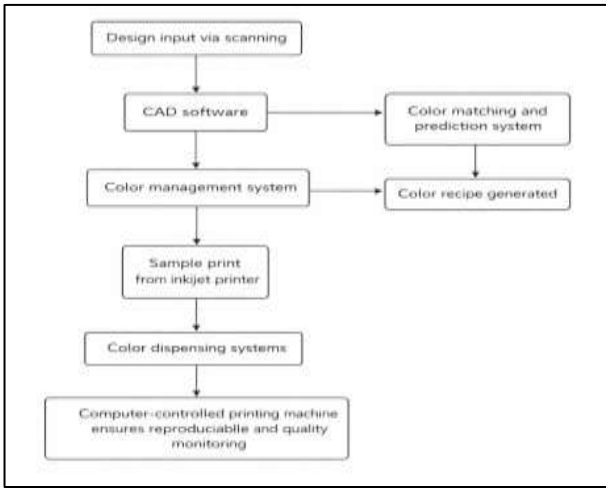

Fig -2 Flow Chart of digital printing using CAD software

3. The Heart of the System: Computer-Aided Design (CAD) Software

CAD software is not just a drawing tool; it is the central link between the designer's idea and the final printed fabric.

3.1 Turning Ideas into Digital Data (Digitization)

The first step is to get a design into the computer. This can be done by:

- **Scanning** a hand-painted design.
- **Drawing directly** in software like Adobe Illustrator (for clean lines and shapes) or Adobe Photoshop (for photos and textures).
- **Creating designs** in specialized textile CAD software like Ned Graphics or Lectra Kaledo, which have tools made just for fabrics (Ujiie, 2006).

Once a design is digital, it never fades, can be emailed anywhere instantly, and can be changed easily (Davis, 2002).

3.2 How CAD Helps Designers

CAD software gives designers new powers and creativity:

- **Creating Repeats:** Software can instantly create a seamless repeating pattern (like on wallpaper or dress fabric), a task that used to take skilled artists days to do by hand.
- **Changing Colours:** A designer can try out dozens of colour combinations for a design with just a few clicks.
- **Experimenting Safely:** Tools like "layers" and "undo" let designers try bold ideas without ruining their work.
- **Building a Library:** Designs and motifs can be saved and reused, making the design process faster over time (Choudhury, 2017).

3.3 Saving Time and Money

CAD software automates the most time-consuming technical tasks:

- **Colour Separation:** For screen printing, each colour needs its own screen. CAD software can accurately separate a complex design into its individual colours digitally in minutes, work that used to take many hours (Choi et al., 2003).
- **Sampling:** A "sample" or "proof" can be printed on the actual fabric directly from the computer file. This eliminates the need to make screens just to check a design, saving weeks of time and thousands of rupees (Owen, 2003).

Design Management for Digital Ink-jet Printing

Digital ink-jet printing is a computer-based system that applies multicolor designs directly onto fabric without using physical templates or screens. This method works from digital design files, which can be easily edited and processed without losing quality. Since no screens are

needed, it saves significant time, reduces material waste, and avoids the use of large amounts of water and chemicals required for screen cleaning. Colors are created by blending printer inks digitally, minimizing ink waste and environmental impact. It also allows for fast design changes, small batch production, and personalized designs, while eliminating the risk of misalignment that can lead to defective products. Using CAD software, designs can be simplified to a manageable number of colors and accurately reproduced. Overall, digital ink-jet printing offers a faster, more flexible, and more sustainable alternative to traditional textile printing methods.

Colour Management in Digital Ink-jet Printing

While CAD systems have made textile design and color manipulation faster and easier, they have not fully solved color communication problems. One major issue is that computer screens mix light (additive color), while printing uses inks on fabric (subtractive color), making it hard to predict exactly how digital colors will look when printed. An ideal digital printing system would accurately interpret designs, predict color recipes, and control the printing process for specific fabrics. To bridge the gap between screen and print, color matching must be improved using reliable databases and automated dispensing systems. Some solutions involve advanced color models and synthetic reflectance curves, but these still face technical challenges like screen calibration, phosphor consistency, and color stability. A practical approach may combine physical color atlases with digital tools, allowing designers to work with objective, real-world color references that have corresponding spectral data. An effective color communication system should be visually intuitive, cover a wide color range, be easy for everyone to use, and be precise and reproducible. Currently, many printers rely on recipe-based systems tied to specific dyes and fabrics, but these are not universal and often require physical samples for customer approval. For true digital integration, more calibrated and maintained systems are needed across the industry to ensure consistent color from design to final print.

4. The Printing Machine: Digital Ink-Jet Technology

While CAD creates the instruction file, the digital ink-jet printer is the machine that carries it out. Its development has been crucial.

4.1 A Brief History of Development

Digital printing on fabric started in Japan in the 1980s but was very expensive. In the 1990s, companies began modifying paper printers for fabric, and chemical companies started making dyes suitable for these printers, which brought costs down. The speed of these machines has been steadily increasing, as seen at major textile machinery shows (ITMA):

- **1995:** Very slow machines, only for making samples.
- **1999:** Machines built for textiles, but still slow.
- **2003:** Speed reached about 150 square metres per hour.
- **2007:** Speed improved to about 300 square metres per hour (Holme, 1999, 2000; Moser, 2003; Yuen et al., 2008).

4.2 How the Printer Works: Print Heads

The print head is the part that sprays the ink. There are two main types:

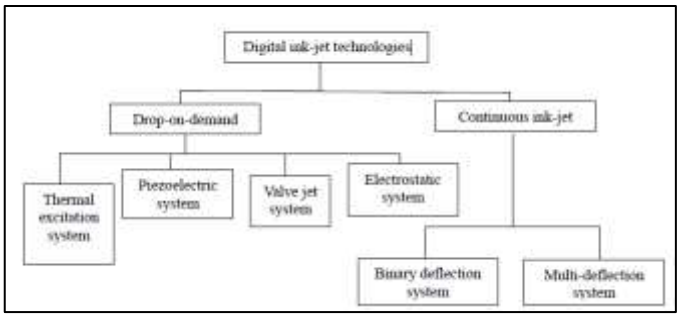

Fig-3 - Digital ink-jet technologies

- **Drop-on-Demand (DOD):** The printer head shoots a tiny drop of ink only when it is needed for the design.
- **Piezoelectric (Piezo):** This is the most common type for high-quality textile printing. A small crystal moves to push the ink out (Fig. 6 in Kan & Yuen, 2012). It is reliable and can produce very fine detail.
- **Thermal/Bubble Jet:** A tiny heater creates a bubble that pushes the ink out. It is cheaper but can clog more easily and the heat can damage some inks.
- **Continuous Ink-Jet (CIJ):** Ink is constantly flowing in a stream, which breaks into droplets. The droplets needed for the design are directed onto the fabric; the rest are recycled. This can be faster but is more complex and expensive (Malik et al., 2005).

5. The Special Ink for Digital Printing

You cannot use the thick paste from screen printing in an ink-jet printer. The ink must be very fluid, like water, but with special properties.

5.1 Important Properties of Digital Ink:

- **Viscosity:** It must be just the right thickness (very low) to flow through the tiny nozzles.
- **Surface Tension:** This affects how the ink forms a droplet and how it spreads on the fabric.
- **Purity:** It must be extremely pure, with no particles that could clog the print head.
- **Colour Strength:** Because very little ink is used, the colourants (dyes) must be very strong and bright (Choi et al., 2004).

5.2 Types of Ink (Based on Fabric):
Different fabrics need different inks to get good, wash-fast colours.

- **Reactive Dye Ink:** Used for natural fibres like **cotton** and **viscose**. The fabric must be pre-treated with alkali. After printing, it is steamed to fix the colour and then washed.
- **Disperse Dye Ink:** Used for **polyester**. Fixed with high heat or steam.
- **Acid Dye Ink:** Used for **wool**, **silk**, and **nylon**. The fabric needs an acid pre-treatment.
- **Pigment Ink:** Can be used on many fibres. It contains coloured particles glued to the fabric with a "binder." It often requires heat to cure the binder (Tyler, 2005; Glover, 2005).

6. Preparing the Fabric: A Critical Step

For most digital printing (except some pigment printing), the fabric cannot be used as it is. It needs **pre-treatment**. This is a chemical bath applied to the fabric before it goes into the printer.

Why is Pre-treatment Needed?

1. **To Control the Ink:** Without it, the watery ink would spread like a drop on blotting paper, causing blurry edges (wicking).
2. **To Make Colours Brighter:** It helps the fabric absorb and hold more dye.
3. **To Provide Fixation Chemicals:** For reactive dyes, the alkali needed for the chemical reaction is applied here, not in the ink (because it would damage the printer).

A typical pre-treatment for cotton involves padding the fabric with a mix of:

- **Sodium Alginate:** A natural thickener that controls ink spread.
- **Urea:** Acts like a sponge during steaming, helping the dye move into the fibre.
- **Sodium Bicarbonate:** The alkali that makes reactive dyes work (Yuen et al., 2004; Hees et al., 2003).

Other Fabric Requirements:
The fabric must also be:

- **Very Clean and Smooth:** Any dust or loose fibres can clog the print head nozzles.
- **Consistently Straight:** The warp and weft threads must be even, or the printed design will be distorted.

7. The Big Challenge: Colour Management

This is one of the hardest parts of digital textile printing. The colour you see on your computer screen is made of light (Red, Green, Blue - **RGB**). The colour on fabric is made by dyes/inks that absorb light (Cyan, Magenta, Yellow, Black - **CMYK**, plus special colours).

The Problem: A bright red on your screen might print as a dull orange on cotton because the ink and fabric interact differently. The texture of the fabric also changes how colour looks (Provost & Kool, 1996).

The Solution (Colour Profiling):

To match colours, a complex calibration is done. The printer prints a chart with hundreds or thousands of colour patches on the specific pre-treated fabric. A special scanner then measures the actual colour of each patch. Software compares what was sent (the digital colour) to what was printed (the actual colour) and creates a custom "profile." This profile tells the printer how to adjust its ink mixtures to get the right colour on that specific fabric and ink combination (Oulton & Young, 2004). This process must be repeated for every type of fabric and ink used.

8. Current Problems and Limits of Digital Printing

Even with all its benefits, digital printing is not perfect yet.

1. **Speed:** Although improving, it is still much slower than a running rotary screen printer. It is best for short runs, not for millions of metres of the same bed sheet.
2. **Cost:** The special inks and pre-treated fabrics are more expensive than materials for screen printing.
3. **Colour Challenges:** Getting perfect, consistent matches for specific "spot colours" (like a brand's logo colour) can be difficult. Achieving very deep, dark colours is also a challenge.
4. **Machine Maintenance:** Print heads are delicate and nozzles can clog, requiring careful maintenance.
5. **Fabric Limits:** Not all fabrics work well. Very stretchy knits, thick towels, or fabrics with a rough pile can be hard to print on reliably.

9. The Impact and Future of Digital Textile Printing

The move to digital is changing the entire industry:

- **For Designers:** They need to be both creative and tech-savvy, understanding software and how their designs will print.
- **For the Supply Chain:** A design can be created in India, sent digitally to a factory in Vietnam, and samples approved the same day. This enables true global production.
- **For the Environment:** Digital printing produces less waste water and chemical runoff than screen printing. More importantly, it allows **on-demand production**, meaning items are only printed when they are ordered, reducing huge amounts of unsold stock and waste (King, 2002).
- **Mass Customization:** It is now possible to let customers design their own T-shirt, curtain, or bag online and have it printed as a single, unique item.

Further Scope:

- **AI-Powered Design:** Software that can help generate patterns or suggest colour ways.
- **3D Simulation:** Using the digital design file to show how a finished dress or sofa will look before any fabric is printed, reducing sample waste even further.
- **Faster, Better Machines:** Continued improvements in print head speed and new types of inks will keep pushing the technology forward.

10. Conclusion

Digital ink-jet printing is revolutionizing the textile industry by enabling agile, customizable, and on-demand production. It marks a shift away from traditional, large-scale standardized runs. Central to this transformation is CAD software, which converts artistic designs into precise digital instructions, expanding creative potential and automating complex tasks. The technology has evolved beyond a mere prototyping tool into a viable production method, driven by advancements in print heads, inks, and colour management. Key advantages include unlimited colours, no repeat-length restrictions, drastically reduced lead times from design to sample, and significant cost savings by eliminating screens and reducing waste and inventory.

Unlimited Design Scope: It eliminates restrictions on the number of colors and the repeat length of patterns, offering superior creative freedom.

Dramatically Faster Process: It reduces the design-to-sample timeline from weeks to just a few hours by eliminating the need for physical screen preparation.

Efficient Digital Workflow: Designers can create, modify, and evaluate pattern variations, colour matches, and print effects directly on a computer screen.
Significant Cost Savings: It removes screen preparation costs, reduces material waste from rejects, and lowers expenses for inventory and labour.

Agile and On-Demand Production: The technology enables quick sampling and short runs, reducing inventory needs and allowing rapid response to market trends.

However, widespread adoption faces several technical challenges. Hardware limitations, particularly in print head technology and printing speed for wider fabrics, need resolution. The specialized inks must meet stringent physical and chemical criteria for compatibility, and a universal ink remains elusive. Furthermore, achieving consistent print quality is highly dependent on meticulous control of fabric characteristics, such as pre-treatment,

surface texture, alignment, and tension during printing. Despite these hurdles, the trajectory is clear. The synergy of digital design and printing powerfully supports modern imperatives of speed, sustainability, and personalization. Thus, it represents not just a new printing technique, but a fundamental transformation in how the textile and fashion industries operate in a global market.

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