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Applications of the digital technologies in textile and fashion industry

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Abstract. Recently, there have been increased demand and applications of digital technologies such as 3D printing, digital printing, radio frequency identification (RFID) and computer vision in textile manufacturing in order to improve the supply chain system and increase customer's satisfaction. Moreover, these technologies help to ensure sustainability and enable manufacturers as well as retailers to respond promptly to market demand by reducing product lead-time. However, there are limited research on in-depth review on the applications of these technologies in textile manufacturing and fashion retailing. This research rigorously review the recent articles related on the applications of 3D printing, digital printing, radio frequency identification (RFID) and artificial intelligence in textile manufacturing. The review reveals that implementation these technologies reduces production cost and increases profitability. The authors also proposed models for the above-mentioned technologies that are applicable in textile and fashion industries.

Keywords: Digital technologies, 3D printing, digital printing, radio frequency identification (RFID), and computer vision.

1. Introduction

The on-going shift of people's lifestyles and retail markets toward various organizational models convey the message the application of digital technologies is now at the center of contemporary debates and scholarly articlescovering wide ranges of disciplines, varying from humanities to science, engineering and technology. Therefore, it has projected that the application of digital technologies such as 3D printing, digital textile printing, radio frequency identification (RFID), and computer vision will noticeablychange all major industrial systems in the coming years[1]–[4]. Digital technologies are based on digitized production techniques that involve the use of digital file, computer aided design (CAD), computer aided manufacturing (CAM), programming languages, sensors, servers, electronic signals etc.The capabilities of these technologies to develop a sustainable future have motivated manufacturers and retailers to transform their supply chains using these technologies[1]. This review paper has focused on the implementation strategies and applications of these major technological advancements, which are also related to Industry 4.0 or fourth industrial revolution trend. This trend is expected to possess huge impacts on the textile and apparel industry in the near future. The second section of this paper reviews the recent research on the applications of the popular digital technologies in the textile industry. The third section presents the prospects, challenges and recommendation related to these technologies. The main scientific contribution of this paper is to proposing model for each of the technologies, which will benefit researchers, textile manufacturers and fashion retailers.

2.1. 3D Printing

2.1.1. Definitions

Chakraborty &Biswas defined 3D printing (3DP) as "a computer assisted design (CAD)/computer assisted manufacturing (CAM) technology where a component or the whole substance is manufactured in a layer-by-layer fashion based on a 3D digital model utilizing liquid or rigid materials"[5]. 3DP is referred to as an additive manufacturing method that facilitates a cost efficient, sustainable and novel fashion design based production technique. Researchers also suggested that this technology would be potential to improves rapid prototyping, sustainability and cost minimization compared to traditional methods [2]. Pre-processing and post processing are two main phases of 3D printing method [5]. The advantage of rapid prototyping and single-stage manufacturing system reduce the lead-time and allows personalization or mass customization of products [6], [7]. Hence, it has motivated textile technologists, fashion designers, retailers and manufacturers to adopt this emerging technology [6].

2.1.2. Process Descriptions

The 3D printing technique starts with the pre-process phase. In this phase the model is designed using CAD software such as AutoCAD, Rhino, 3Ds Max etc. Then the software is instructed to divide the model into horizontal layers having x and y dimensions. The CAD controlled digital file then sends signals to printer to print the layers based on the predefined coordinates [7], [10]. Then the data and instructions are sent to the CAM part of the machine, which enables the system to build the final shape of the object. The final phase includes different finishing tasks including sanding, polishing and painting of the product followed by removing the unwanted edges[2], [7]–[10]. The resolution required to produce textile structure needs to be miniscule and accurate because of replicating the fabric patternprecisely [7]–[10]. The most commonly used raw materials to produce the filaments required for 3DP are Acrylonitrile Butadiene Styrene (ABS), Poly Lactic Acid (PLA) and Poly Vinyl Alcohol

(PVA). The 3DP technologies applied to produce 3DP textiles and fashion products, can be classified into (i) stereolithography (SLA), (ii) selective laser sintering (SLS), (iii) inkjet printing, (iv) binder jettingand (v) fused deposition modeling (FDM) techniques [2], [7], [11]. Stereolithography involves the use of liquid plastic based photopolymer resin and ultra-violet (UV) laser, where the UV laser is applied to harden the object forming layers[7]. Selective laser sintering involves the interaction between the laser beam and the powder to print any types of polymers, metals, ceramics and composites based objects [12]. In fused deposition modeling a wire-shaped thin production-grade filament thermoplastic filament is melted inside a nozzle and extruded through its head onto a printing bed by forming layers [13]. Binder jetting is a 3D printing method, which utilizes glue or binder bonding agents to fuse the powder materials and subsequently form the successive layers of powder materials to build the 3D printed products [7]. In inkjet printing, the liquid ink is heated to form bubbles in the ink reservoir, which propels out the ink droplet through a infinitesimal orifice of the printing head [14].

2.1.3. Applications in Textile and Fashion Manufacturing

3D printing enables fashion designers and retailers to create personalized clothing design, enrich designer's design requirements, ensure shorter lead-time and reduce material wastage compared to the conventional manufacturing process and enhance product quality [15]–[17]. Besides, 3DP technique enables designers to apply computer aided design and fabrication to produce complex as well as flexible structures. 3D printed textiles are now extensively used have in the aerospace, medical and food industries. Besides, 3D printing will make it easier for the designers, manufacturers and retailers to respond quickly to the consumers by designing a sustainable supply chain. The continuous research progress on combining soft fibers with filaments will steadily increase the acceptance of 3D printed products among consumers.The 3D printed add-on part can be used extensively in producing athletic footwear, smart clothing laced with sensors, sports gears and medical textiles. 3DP can also be used to produce fire gears and other protective clothing. NASA engineers have developed 3DP fabrics, which can provide protection against severe conditions in the space[2], [15]–[17]. Researchers showed the addition of the shelf fabric to the rigid plastic in order to add various soft properties to the 3D printed textile product [18]. The 3D printing of yarn onto the felt has introduced the procedure of making 3D printed Teddy Bears[19]. Additionally, the similar procedure has been adopted to carry out high voltage electro-spinning to print yarn, using filament based on Poly Lactic Acid. The 3D printed chainmail fabric produced by researchers has showed the possibilities of fabricatingwearable textiles[20].Since, 3D printed textile and fashion production is still at its niche and it is too early to use 3D printed apparel items for day-to-day purposes, manufacturers and retailers can at least produce 3D printed motif or lace structures in order to attach them with the traditional garment products, which has been proposed below through Fig. 1-

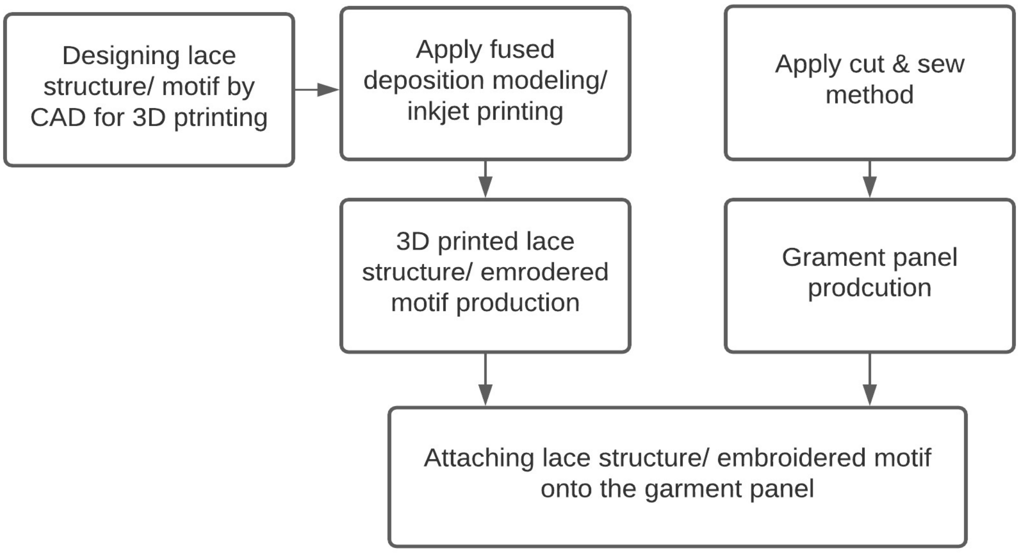

Fig. 1: Application of 3D printing to produce 3D printed lace structure and motif

2.2. Digital Printing

2.2.1. Definitions

Digital printing can be defined as an ink jet printing method using colorants onto the fabric. This printing method is also referred to as Direct to garment printing or DTG as smaller designs can be printed directly onto the t-shirts and dresses [21]. Textile digital printing begun in the 1990s in the form of prototypes to print small fabric batches for niche market products. Developments over the last 30 years have been huge. The digital printing market is now abundant with different types of novel ingredients and technological developments to make a worldwide impact. In digital printing thousands of colors can be printed based on the cyan–magenta–yellow–black (CMYK) color gamut [22]. By digital printing more designs and color variants can be obtained in a shorter time than traditional printing. Most importantly there is no color limitation for producing fine details and aesthetic patterns [23].

2.2.2. Process Descriptions

With the digital printing machines special designs with too small repeat sizes, high resolutions, thin lines, complicated or soft or photographic patterns and a large variety of colors can be produced. The popular printing machines are MS JP-6, MS JP-7, MS LARIO, RENOUR etc. These machines can be single pass type or scanner type. With the digital printing machine manufacturers can produce designs at high resolutions up to 1200 dpi, which is 2 to 3 times higher than that of traditional printing. With digital printing machine it is possible to print thin lines of 20-30 microns. Graphic design programs are used to produce half tone colors having 0 to 256 levels of density differences. It allows obtaining 90% of the actual levels by digital printing, whereas traditional printing allows achieving 40%-50%. Hence, digital printing facilitates excellent color registration, dimensional accuracy and faster yet cheaper design process. The process starts with designing the pattern using Adobe Photoshop, Adobe Illustrator, Ramsete, and Corel Draw [23]. Then the fabric is pretreated using thickener, soda ash, salt and urea. Then the pre-treated fabric is fed to machine and the inks are set. The design produced in the design is sent to machine via a connected server. Once the operator starts the machine, the design starts to be printed on the fabric[21], [24]–[27]. After the fabric is printed, it is fed to the steaming machine in case of cotton fabric printed with reactive ink or curing/drying machine in case of polyester fabric printed with disperse ink. Manufacturers also use various finishing agents such as silicon softener to produce smooth hand feel [21], [24]–[27] The steaming temperature used to post-treat the printed fabric with reactive ink is usually 105^{0}c to 110^{0}c. The time required to post-treat the fabric is usually from 10s to 20s. Researchers showed that with the change of the fabric structure, machine type, chemical proportion and after-treatment factors color gamut, wicking properties and fastness properties change as well [21], [24]–[27].

2.2.3. Applications in Textile and Fashion Manufacturing

Digital textile printing is now being widely used in roll-to-roll fabric printing, garment panel printing and even in electronic textile printing. Digital printed fabric can be used as banner as well [21], [28], [29]. Researchers use conductive ink to print circuits on the fabric. Researchers also used photovoltaic flexible thin film of various sizes ranging from 2x4in to 8.5x11 in sheets to print devices including Burton Shield iPOD Jacket, Menswear Fall Sensing Shirt, and Shimadzu DataGlass [21], [28], [29]. The effective incorporation of photovoltaic thin film cells with wearable textile or garments is tightly tied to consumers' fashion concept. Digital textile printing facilitates the incorporation of components into a printed design that matches the pattern of a specific component [21], [28], [29]. Direct digital textile printing technology allows users to print designs directly from the computer onto the fabric. The application of digital printing allow wide variety of garments to be made from different types of printed small batch of fabrics, which eliminates the requirement of using a large volume of fabric [21], [28], [29]. Digital printed fabric sheet can also be used to make footwear at low cost [30]. Based on these research the authors proposed the following digital printed electronic textile or e-textile manufacturing process, as shown in Fig. 2.

Fig. 2: Application of digital printing to produce of fabric patch for e-textiles

2.3. Radio frequency identification (RFID)

2.3.1. Definitions

The application of RFID technology and its benefits in garment manufacturing has not been completely explored [31]. Moreover, researchers mostly investigated it from theoretical perspectives rather than practical approaches. So, more empirical researches on the applications and impacts of RFID on garment manufacturing processes should be conducted [31], [32]. This study will present the different applications of RFID technology and various impacts or competitive advantages of using this technology in textile manufacturing industry. The discussion of RFID applications and its impacts will help manufacturers to develop their technology roadmap as well.

2.3.2. Process Descriptions

RFID system consists of a RFID, reader and software solution. The tag consists of a chip that stores data in it and an antenna that transmits the data from the chip to reader [31], [33], [34]. The readers can also be kept at the entry and exit gates of production floor and warehouse [35]. There are four different types of RFID named as ultra-high frequency (UHF), low frequency, high frequency and microwave tags [33]. Ultra-high frequency (UHF) tags are generally applied in textile, apparel and fashion industry because of its ability of reading multiple items simultaneously [31], [32], [35]. When the RFID tags are attached to a fabric bundle or garment, then the tag transfers the digital data to the reader via an antenna, which is subsequently transmitted to the central processing unit (CPU) of the computer through the radio waves. Then the software installed into the computer system directly interprets the data retrieved from the RFID tag [33].

2.3.3. Applications in Textile and Fashion Manufacturing

An immense amount of inventory information and production data are gathered and exchanged among different departments during material receiving, garment production and product delivering to next section [36]–[38]. If RFID tags are installed at every stages of textile manufacturing processes, then the wireless transmission of data will help to generate report instantly based on the data collected from fabric cutting, garment sewing, finishing, quality inspection and inventory departments. Hence, it would enable the textile manufacturers to control productivity, inventory, and delivery. Thus, it would help the industries to reduce product loss and production cost [31], [32], [39]. The use of RFID tags and readers along the production lines would help manufacturers to get real-time data of material input and production output from every department of the industry [31], [32], [39]. Hence, they would be able to compare actual and projected standard production quantity, track the work-in-process (WIP) [32] and identify bottlenecks in the production line[40], [41]. According to [41] the use of RFID in inventory management can reduce material shortage by 3.28% and material left over by 3.45%. Researcher showed that a denim manufacturing industry could gain a net profit, twice of the initial investment within the first five years of RFID implementation[32]. According to [42], the installation of RFID can help to increase profit by 27% by reducing lead-time upto 30%. Besides, textile and garment manufacturers can reduce the unnecessary overtime-working hours by 10% based on the RFID generated production report and staff performance [31].

Based on the above process description and applications of RFID in textile and garment can manufacturing industry, the authors presented the following model of RFID installation in the industry. The following Fig. 3 shows the integration of RFID tags and chips throughout the entire textile manufacturing and processing supply chain.

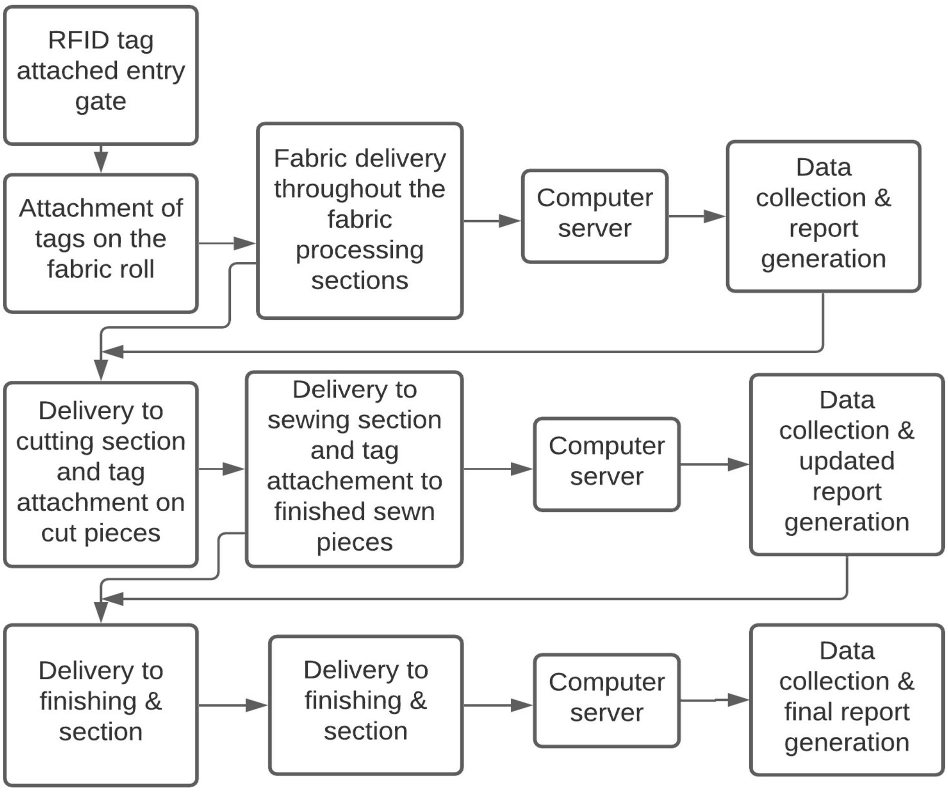

Fig. 3: Application of RFID in a textile and apparel manufacturing industry

2.4. Computer Vision

2.4.1. Definition

Computer vision, a branch artificial intelligence was born in 1950s, which uses input images to as make computer understand and predict about the real world based on the given data. The development of the computer vision technique has showed a growing prospect in the field of robotics and enabled the robot to have a visual ability almost identical human. The generalized version of computer vision technique contains features of both of image processing and pattern recognition techniques[43], [44]. The Marr theory proposed in the 1980s presented a three-layer visual representation and processing architecture, which reinforced the application of computer vision in the field of artificial intelligence [45]. The use of deep learning in computer vision has been very frequent in the recent years [46], [47]. The evolution of computer vision technique contributed significantly in the defect detection as well. The growing importance of quality management has inspired researchers to conduct experiments on real-time automatic fabric inspection and on-loom defect detection using computer vision [3], [48].

2.4.2. Process Descriptions

Researchers have used different image processing and image classification methods used in automatic textile defect detection till to date. These techniques can be classified into five approaches- structural, statistical, spectral, model based and learning based approaches. Structural approach considers product surface texture as an essential element of textural primitives. Statistical approach uses statistical expressionsto analyze and identify textural structureson the basis of the product surface classification. Spectral approach is generally designed to generalize basic texture provided with spatial layout rules. Model-based approaches help in the identification and synthesis of the texture. Learning approach is formulated using supervised technique, which divides the textures into two defectiveand defect free image categories[49]. These techniques have been used to develop different prototypes by researchers [3], [48]–[50]. Chakraborty et al. demonstrated an experimental set up of real-time automatic fabric inspection and on-machine defect detection in their research[51]. Their model consisted of an illumination unit and camera attachment unit. The illumination source had red LED strips uniformly distributed across the machine to ensure a smooth image acquisition quality and better performance of defect detection algorithm. Researchers also developed a prototype to evaluate their real-time defect detection algorithm[52]. This prototype had a line-scan camera traversing along the width of the machine to capture the image of fabrics being produced moving over rollers. Four cameras were used with localization resolution of 0.2mm/pixel to cover 1.6 m transversal. The back light illumination was also a critical element, as it ensures uniform image acquisition throughout the process. The data of the captured image were transferred to the image acquisition and processing card through camera link interface.

2.4.3. Applications of Computer Vision in Textile and Fashion Manufacturing

[53] applied probabilistic neural network (PNN) model to classify neps on the basis of the surface textures extracted from 300 images of yarn neps. Researchers applied otsu thresholding algorithm to detect theprojecting fibers and yarn hairiness[54]. There has been also research on developing a system in order to detect knit fabrics defects such as hole, oil spot, dropped stitches and knot using image processing techniques and extract featuresand fabric defect detection using CNN [1]. Researchers aloproposed a real time circular knit fabric inspection system to detect defects including needle breakages, hole etc. during fabric productionCNN to[55]. Moreover, there have been research on the application of deep learning based convolutional neural network (CNN)model to identify various woven fabric defects includingfabric hole, double weft, broken yarn and thick &thin places[56]. Their proposed model surpassed the performance of other contemporary classification algorithms. Researchersalso showed an unsupervised method for detecting woven fabric defects such as broken end, hole, stain etc[57].There has been development of model to detect defects in printed fabric using Gabor filtering technique[58], where distance-matching function was utilized to detect defects such as broken yarn, fabric holes, yarn knots and thick & thin yarn. Researchers also proposed deep CNN based print fabric defect detection model using real-world print fabric images[59], which would be more effective in real-time defect detection compared to conventional classification algorithms such as support vector machine (SVM) and k-Nearest Neighbor (kNN).

Based on the above process description, applications and performance of deep CNN mentioned by researchersit can be stated that deep convolutional neural network should be more frequently used in textile and garment manufacturing industry, as this network system is considered a strong tool for image classification and deep neural network[56], [59]. Based on this phenomenon, the authors presented the following model of automatic knit fabric defect detection system in the industry, as shown in Fig. 4. This can be applicable in woven and printed fabric manufacturing industries as well.

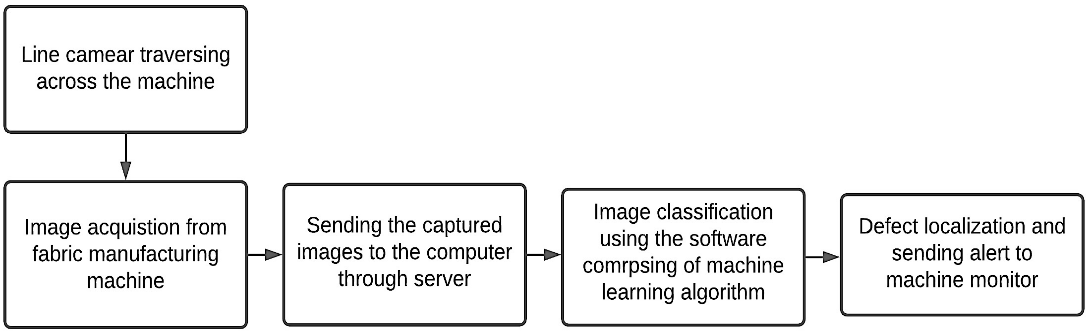

Fig. 4: Application of computer vision for real-time defect detection of knitted fabric

3. Prospects, Challenges and Recommendations

Application of digital technologies in textile manufacturing is expanding day-by-day. Manufacturers must need to adopt these technologies to make their supply chain more efficient than earlier. Application of these technologies in export based Asian countries will help to produce high quality fabric in short lead-time. There will be new job opportunities in the textile and apparel manufacturing industry as well. The models proposed by the authors in the previous sections will also benefit textile manufacturers to adopt these digital technologies in their textile manufacturing supply chain. Application of digital technologies will be also helpful for Western countries as well. These technologies eliminate too much reliance on manual labor, which will reduce the production cost. At the same time, the existing manpower can be trained with necessary technical skills, which will create new job opportunities in the market. The application of these technologies will also ensure sustainable textile manufacturing processes by reducing fabric wastage and increasing quality[60], [61]. These technologies would also benefit textile, apparel and fashion manufacturers during the post COVID-19 period by modifying the existing supply chain models[62].

4. Conclusion

Although the application of digital technologies such as is yet to be popular and common in textile and fashion manufacturing, it would be inevitable in the near future. The application of 3D printing, digital printing, radio frequency identification (RFID) and computer vision will not only be helpful in reducing production time and cost, but also in increasing supply chain efficiency and overall profit. These technologies are promising in terms of ensuring sustainability as well. Manufacturers of the Asian countries can start implementing the models proposed in this article as an initial approach, so that these technologies become common there in the coming years.

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